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Advances in Carrier Telegraph Transmission

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Introduction

IN the comparatively short period which has elapsed since its commercial introduction in a practical form, the voice-frequency carrier method of operating telegraph has risen to a position of preeminence and is becoming the outstanding means for providing telegraph facilities over main toll routes.

Since the original installation, improvements have been made in the carrier supply, level-compensating devices, maintenance facilities, and in numerous other specific physical parts of the system. Operating speeds have also gone up, and the number of telegraph channels per telephone circuit has been increased. Furthermore, this system, originally designed for cable circuits operating at voice frequencies, has been applied to open-wire lines and adapted by remodulation to other frequency ranges, in particular to those occupied by existing carrier-telephone systems. Some of the chief advances, however, have been of a more intangible nature, not the least of these being the clearer insight which experience and extended tests have given into the possibilities and limitations of carrier-telegraph systems with respect to interference and other causes of signal distortion.

As a result of the success attained by the carrier-telegraph system for open-wire lines,[1, 2] which had been in commercial service in the Bell System since 1918, this company's engineers turned their attention to the adaptation to cable circuits of the carrier method of transmission for telegraph purposes. Following this work and extensive field trials, the voice-frequency carrier-telegraph system went into commercial use in the Bell System in 1923.[3] The initial installation consisted of ten two-way or duplex channels between New York and Pittsburgh, giving an aggregate channel mileage of 3800 miles (6120 km.) including both directions of transmission. Since then, the application of this

mode of transmission has spread rapidly so that in spite of the intervening period of retarded business activity it now provides about $1\frac{1}{2}$ million miles (2.4×10^6 km.) of high-grade circuits throughout the Bell System. Its use with variations has extended to other countries so that it bids fair to become an outstanding means for providing overland telegraph facilities, particularly for long distances, where the service is exacting. As indicating the general trend, it may be stated that in England alone about 1700 voice-frequency telegraph channels were reported as available for operation at the end of 1938.[4]

It is interesting to note the role played by carrier telegraph in the evolution of the art of telegraphy. The three major telegraph systems up to about 1890 were those of Hughes on the Continent, Wheatstone in England, and the manual Morse system in the United States. As electrical communication reached out to greater and greater distances, the desire to utilize costly lines more effectively led inventors to concentrate their efforts in two different directions; namely, the development of high-speed systems and of multiplex systems. In high-speed systems, the object, as the name implies, is to secure increased line output by speeding transmission well beyond the ability of a single operator. These devices are characterized by automatic transmitters which can be supplied with perforated tape prepared in advance by a number of individuals. Typical high-speed systems are the Wheatstone automatic, the Murray automatic, the Siemens and Halske high-speed, and the Creed high-speed.[5]

The first efforts at multiplexing circuits were based upon the suggestions of Gintl and Highton, who proposed to take advantage of directional and magnitude effects respectively, and whose ideas were brought together by Edison in his invention of the quadruplex. The multiplex system as we know it, however, was the invention of Baudot, who, putting into practical form a suggestion made by Moses G. Farmer as far back as 1853, produced a system whereby the line was assigned successively to a number of operators. This process had the great advantage that while maintaining the line speed which economy made imperative, it permitted a number of messages to be transmitted simultaneously without delay and with each operator working at his normal pace. The chief examples of the multiplex are the Baudot, Murray, and American.[5, 6]

Owing to the advantages of these higher output systems, the older methods of operation were gradually supplanted for the longer commercial message circuits. This was particularly true in Europe, since certain conditions operating in America tended to favor the survival of the simple Morse arrangement; the chief of these being the avail-

ability of large numbers of composited and simplexed circuits, most of which were used in private line service,[7] and the low traffic density on many long multi-section circuits, making it desirable to provide intermediate operating points. By about 1920, the weight of evidence definitely favored the multiplex method of exploitation over the use of the high-speed printer.[6] It was at about this point in telegraph history that the carrier telegraph method of subdividing the line capacity made its appearance and, through its superior flexibility and lesser intricacy of operation, began gradually to supersede the distributor methods of multiplexing circuits for many types of services.

While voice-frequency telegraphy was foreshadowed by Elisha Gray's harmonic telegraph,[8] which was exhibited at the Third French International Exposition in 1878 and at the Electrical Exhibition in Paris in 1881,[9] its practical embodiment had to await the invention of the electrical filter by Campbell, that of the audion by DeForest, and the production of effective means for generating alternating currents of acoustic frequencies.

The success of this system rests mainly upon its adaptability to economical operation over telephone circuits by making effective use of the whole frequency band usually allocated to the voice, and in requiring similar transmission characteristics. Henceforth, every advance in telephony directed to an improvement of the transmitting medium contributes as well towards the improvement of telegraphy; the economies of wide-band carrier telephony, the improved equalization and regulation of circuits, the reduction of interference and the elimination of crosstalk, all tend to make the telegraph a more dependable and efficient tool for modern industry and modern living. Thus telegraphy, one of the oldest of the electrical arts, having fathered the telephone, now finds, within the great technical structure which the latter has created, a fertile medium for the development of its usefulness, not as a competitive but as a complementary service. Thanks to voice-frequency telegraphy, wherever the telephone reaches, a high-speed, reliable, record-form of telegraph may follow. This has brought about a great simplification of the problem of interconnection in such large communication networks as the international postal area in Europe and the Bell System in our own country.

Furthermore, carrier telegraphy has doubtless been a means of advancing the fortunes of the start-stop teletypewriter,[10] by subdividing the frequency band to such an extent that one channel may be economically assigned to a single operator working at normal speed. It has also been a factor in simplifying the switching problems presented by the extensive introduction of teletypewriter exchange (TWX) service.[11]

The purpose of this paper is to describe the principal transmission developments which have taken place in the voice-frequency system since the first commercial installation, to present some of its operating characteristics, and to outline advances in maintenance methods which have developed during this period.

There has been marked and steady improvement in the quality of the service rendered by the voice-frequency telegraph circuits during the last decade within the Bell organization, and while it would be unfair to overlook the part which imaginative management, employee cooperation, and similar factors have played in securing this desirable result, it appears certain that a good deal of it is to be credited to those physical improvements and advances in testing and operating procedures which we are about to recite.

Extensions in Utilized Frequency Range

While the greater part of past experience has been had with the application of voice-frequency systems to extra-light-loaded four-wire cable circuits,* a considerable mileage now utilizes other types of telephone facilities, particularly high-frequency carrier open-wire lines [13] through the less densely populated regions. These latter applications are interesting to the transmission engineer because the association of telephone and telegraph in the same repeaters brings into view new problems which will doubtless grow in importance as the use of broad-band carrier systems becomes more extensive. A typical voice-frequency carrier-telegraph circuit is shown in Fig. 1. It consists of a section of four-wire cable connected in tandem with a three-channel type "C" carrier-telephone circuit,[14, 15] without mechanical repetition at the junction point. The telegraph power is appropriately modified to suit the requirements of the two media by means of pads and amplifiers P at the point where they join. In addition to this, the remaining telephone circuits operating through the same carrier repeaters are equipped with volume limiters [16] to prevent voice-energy peaks, which contribute little if any to telephone quality, from overloading the amplifiers, thereby causing excessive distortion to the telegraph.

Shortly after the initial voice-frequency telegraph installation in cables the number of channels was extended from 10 to 12 by the addition of two channels at the upper end of the frequency range, corresponding to carrier frequencies of 2125 and 2295 cycles.

* These circuits are designated as H44. They consist of 19 AWG conductors, loaded with 44-millihenry coils 6000 ft. (1830 m.) apart, with four-wire repeaters spaced at approximately 50-mile (80.5 km.) intervals.[12]

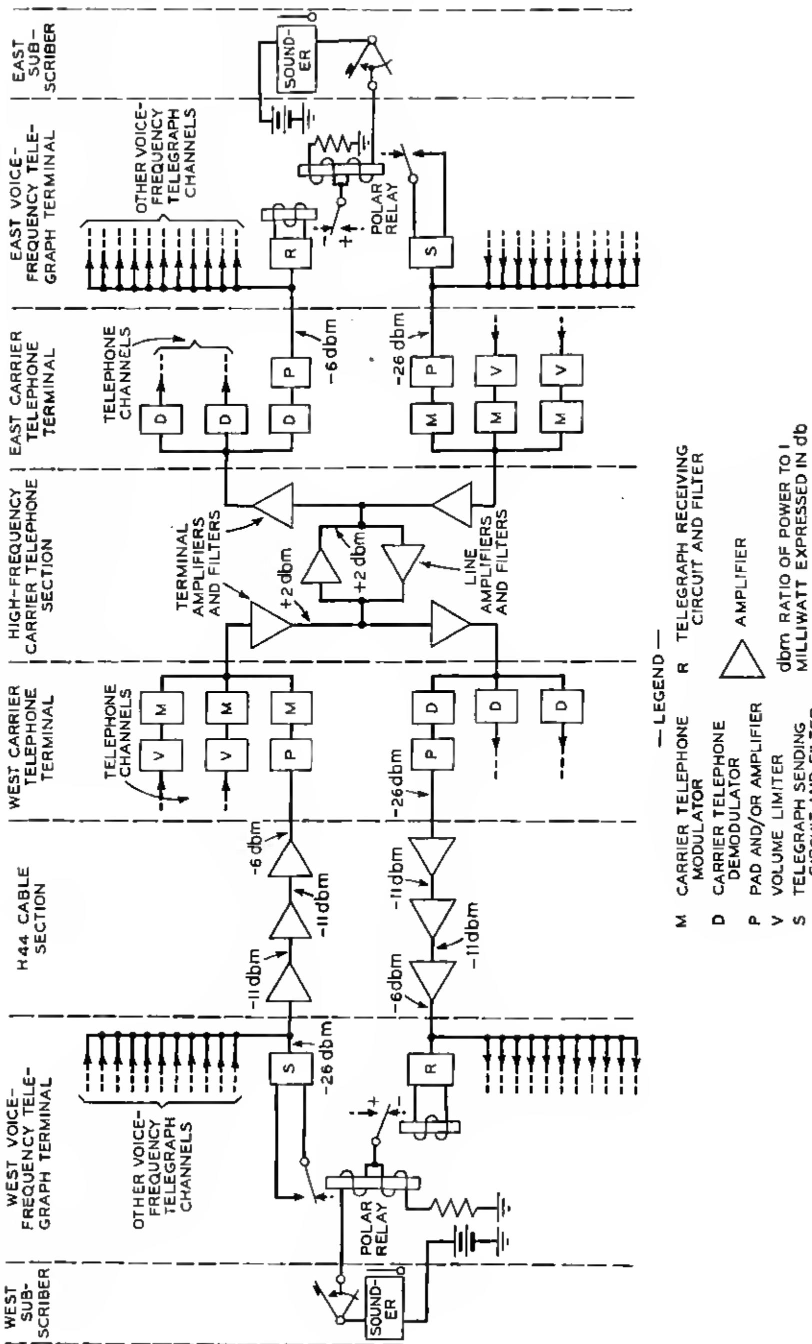

Fig. 1—Typical carrier-telegraph circuit.

At a later date the extensive introduction of H44 circuits, with their relatively high cut-off, was thought to make it desirable to consider a further extension of the frequency band utilized by the telegraph. However, in view of the fact that the then existing state of the art of filter design made it impractical to produce economical filters of the required narrow band-width but having the desired high mid-band frequency, it was decided to develop a carrier-telegraph system suitable for use between dense traffic centers by superposing two standard 12-channel systems over the same cable pair. This was accomplished by causing the various signaling frequencies of one system to modulate a single secondary carrier, thereby transposing all the frequencies of this voice-frequency system to a frequency range above that of a normal voice-frequency system operating over the same cable pair.

The line circuit used with this double system was required to transmit a range of frequencies from about 350 cycles to 4400 cycles, and the stability within this range had to be such as not to cause excessive bias in any channel with the regulating methods available at that time. In order to secure this result, it was necessary to change the transmission characteristic of all repeaters from that used for ordinary four-wire telephone or voice-frequency telegraph transmission and, furthermore, to modify somewhat the regulating repeaters in order to maintain the desired transmission characteristics with changes in temperature.

No changes of any kind were required in the voice-frequency telegraph terminals. The channel frequencies on the line were arranged to extend uninterruptedly at 170-cycle intervals from 425 cycles to 4335 cycles.

This arrangement was called the "double-modulation" system, because operation of two voice-frequency carrier telegraph systems over the same circuit was realized by causing all the channel frequencies of one of these two systems to pass through a common modulator, where a second modulation took place; the individual frequencies of each channel being already considered as having been modulated by the sending relays. A single secondary carrier-frequency was used which was common to all the channels. The allocation of frequencies, which was identical for both directions of transmission, will be readily understood by referring to Fig. 2*B*. The general principle of operation is illustrated in Fig. 2*A*, which shows transmission from west to east, it being understood that the arrangement from east to west is identical. The voice-frequency system denoted as No. 2 will be seen not to differ in any way from the earlier arrangement except that signals from all twelve channels traverse low-pass grouping filters at the sending and receiving terminals. In the case of voice-frequency system No. 1,

however, all the frequencies are passed through a modulator, where they are transposed as a group to a position above those of system No. 2. The lower sideband of the secondary carrier is used, so that the order of the channels is reversed on the line. After modulation, this

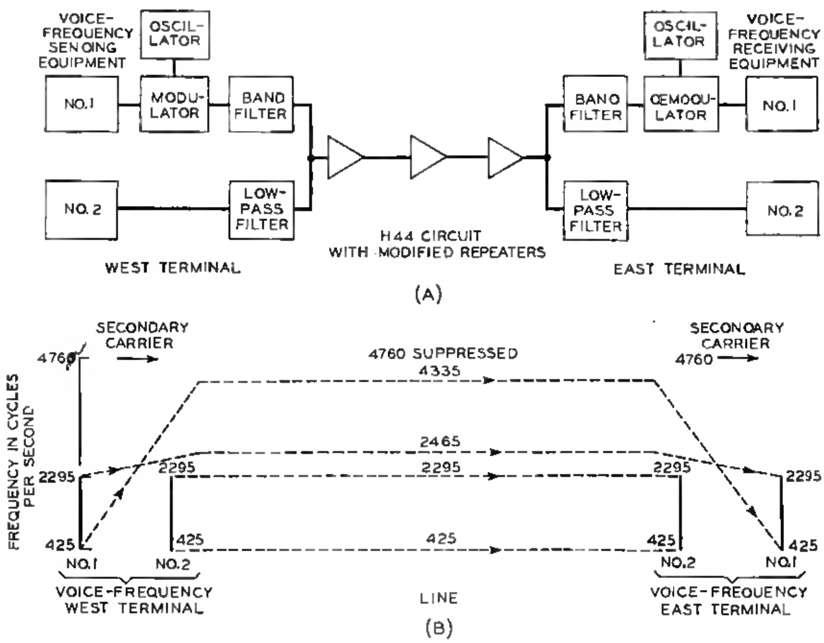

Fig. 2—Double-modulation telegraph system. *A*. Block diagram for one direction of transmission. *B*. Frequency relations at terminals and on the line.

group of frequencies passes through a sending band filter, which elminates all the unwanted frequencies, thereby preventing useless overloading of the repeaters and the creation of undesired modulation products therein. The two groups of frequencies pass through common repeaters over the modified H44 circuit and are then separated at the receiving terminal by a combination of filters similar to the one at the transmitting end of the circuit. The signals pertaining to voice-frequency system No. 1 are next demodulated by a secondary carrier having the same frequency as that used at the sending end and thereby reduced to a frequency range adaptable to the standard terminal equipment. The modulators and demodulators were provided with separate oscillators at both ends of the circuit.

Both modulators and demodulators were of the push-pull type and were arranged as grid-current modulators [17] instead of as plate-current

modulators such as were then current in telephone practice. In the case of grid-current modulators, the necessary non-linear characteristic is obtained by so constructing the input circuit that the voltage between the grid and filament of the modulating tubes does not vary directly with the voltage impressed upon the modulator input, while plate modulation is suppressed; in the case of plate-current modulators, on the other hand, there is a linear relation between the grid-to-filament voltage and the voltage impressed upon the modulator input, but advantage is taken of the fact that the plate current does not vary directly with the grid voltage to secure the desired modulation effect. The reason for using grid-current modulators of this type was that the increased power output secured thereby made it possible to produce the required output levels without auxiliary amplifiers.

The trial double-modulation system performed satisfactorily under commercial conditions although the upper group or remodulated system was somewhat less satisfactory than the standard. This wide range system has not been used, however, partly because of reduced demand due to economic conditions and partly because advances in the art of filter design now make possible a considerable extension on a single modulation basis; furthermore, the increasingly wide use of carrier telephone circuits makes it desirable to restrict the band width used by a voice-frequency telegraph system to the frequency range normally assigned to a telephone channel.

Signal Distortion

Improvements in transmission amount essentially to reductions in signal distortion. The principal sources of such distortion [18, 19] are:

Type of Distortion	Source
Characteristic	Filter characteristics.
	Wave shaping characteristic of detectors.
Bias	Variations in circuit net-loss.
	Battery variations at terminals.
	Variations in carrier-current generator voltage.
	Gradual frequency changes.
	High-resistance sending-relay contacts.
	Asymmetrical relay adjustments.
Fortuitous	Noise.
	Lightning.
	Functional switching operations.
	Change in repeater gain with load.
	Intermodulation of several channels in repeaters.
	Infiltration from adjacent telegraph channels.
	Relay contact troubles.
	Irregularities in relay operation.
	Rapid variations in carrier frequencies.

Characteristic distortion attributable to the telegraph channel filters is not an important limitation at the speeds now generally used and need not detain us as it has been discussed at length elsewhere.[20, 21, 22] It might be stated, however, that while the frequency band used at the present time, which provides an effective width of about 110 cycles, allows some margin of transmission with present speeds, the proposition of reducing the spacing of carriers is not very attractive for a number of reasons, among which may be mentioned the reduction in cost per cycle of band width due to the development of carrier-telephone systems, the possibility that higher speed requirements may ultimately make the present spacing desirable, and the greater degree of maintenance demanded by a system designed with less liberal operating margins where a number of sections are operated in tandem. With respect to the speed factor, it may be observed that service is already being rendered commercially in several cases at 75 words per minute, and still higher speeds have been used.

Bias

Variations in circuit loss consequent upon changes in temperature, battery voltages, etc., are a major factor in determining signal distortion, as will be seen by reference to Fig. 3 which shows graphically the

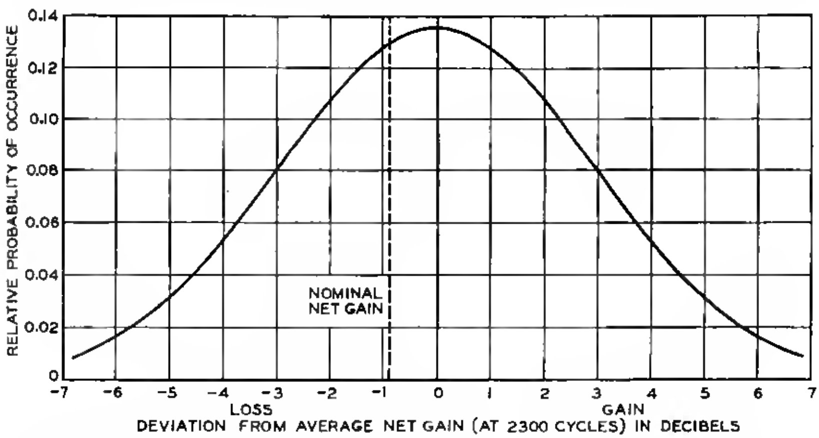

Fig. 3—Probable distribution of net-gain variations at 2300 cycles. H44 circuits about 1000 miles (1600 km.) long. Includes both differences between circuits and variations with time.

approximate manner in which a particular group of 19 gauge H44 circuits about 1000 miles (1600 km.) in length varied through a one-year cycle at the frequency of channel 12 (2295 cycles). The effective

range of variations with respect to the optimum input level to the detector depends on the method by which the sensitivity of the latter is adjusted. Two methods have particular advantages: In one of these the detectors are adjusted for a nominal received level which is made the same for all the channels. This is the method usually employed for cable circuits. It permits adjusting the detectors at any time without reference to the particular line with which they are to be used and without the assistance of an attendant at the distant station. It will be evident that the departures from optimum line gain must then be reckoned from this nominal net circuit-gain, which in the illustration is shown as being .9 db below the actual mean value. This discrepancy is principally due to imperfect equalization of the line. In general it is least in the neighborhood of 1000 cycles and increases progressively as one goes away from this frequency. Furthermore, the standard deviation of the distribution curve increases generally in the same manner, so that for a 12-channel system the condition illustrated is perhaps the most unfavorable one.

A second method of lining up is to adjust the detector sensitivity so as to give unbiased operation with signals transmitted from the distant station and with the line loss whatever it happens to be at the moment. On the average, and in the long run, the effect of this procedure is to restore the symmetry of the variations, but the standard deviation is multiplied by a factor equal to the square root of 2. This is because the occurrence of a given departure from the optimum level is then further conditioned by the particular net gain which happens to exist at the time the detector is adjusted, and the chance of a gain of this particular value is given, of course, by the same distribution which has just been discussed. Most of this increased latitude in variations can be eliminated, however, by seasonal adjustments; a procedure which is evidently of no help when the first method is followed. This second method has been found useful on open-wire circuits because the average net loss of telephone channels over these facilities depends somewhat on their frequency allocation and varies more widely than is the case with cable circuits.

If no provision were made to compensate for these line-variation effects the result would be a rapid change in bias as the level at the input of the detector departs from its optimum value. This is shown for a typical telegraph channel by the dotted line in Fig. 4. By the use of a *level compensator* associated with each individual detector a great improvement may be obtained, however, the bias variations being reduced to those illustrated typically by the full line in the same drawing. The resulting changes in teletypewriter orientation

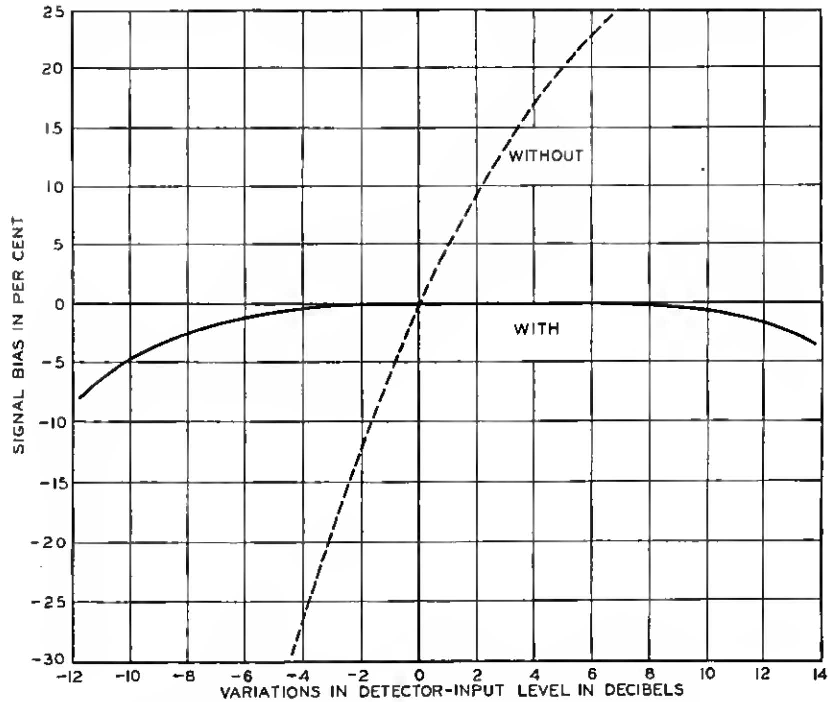

Fig. 4—Effect of level compensator. Signal bias vs. variations in detector input level. Signaling speed 23 dots per second.

range when the level compensator is used are of the order shown in Fig. 5, indicating satisfactory operation over extensive changes in circuit loss. It will be seen that in the absence of a level compensator a single-section telegraph circuit operating at a speed of 23 d.p.s. (46

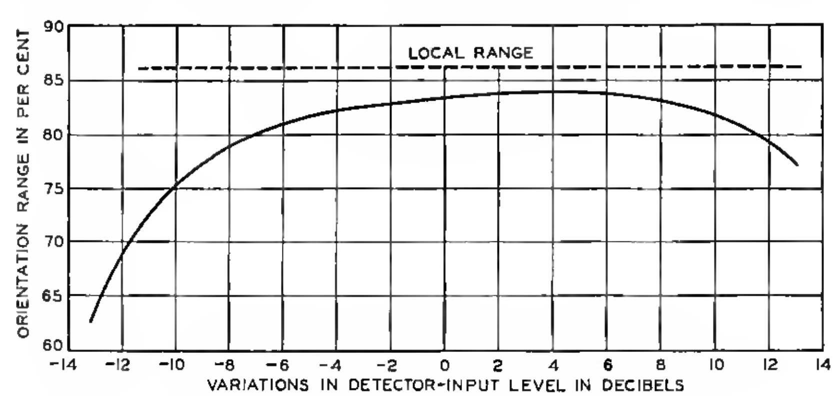

Fig. 5—Teletypewriter orientation-range vs. variations in detector input-level.

bauds) may exhibit a change in signal bias of 4 per cent or more for each db change in input level. With a level compensator of the type described herein, the bias may be kept within a range of $\pm$ 2 per cent for a variation in input level of $\pm$ 8 db.

The elimination of any considerable bias variations in individual telegraph sections due to level changes which usually occur in practice is particularly important in the case of multi-section * circuits. As a result of this improvement it has been found feasible under test conditions to operate satisfactorily as many as 10 telegraph sections in tandem at 60 words per minute for long periods without objectionable bias variations due to level changes and without the use of regenerative telegraph repeaters. In practice, however, other considerations usually make it desirable to use a regenerative repeater when the number of sections in tandem exceeds 4.

The greater part of the effective changes in received level in a given circuit is due to temperature changes which are imperfectly compensated for by the regulators, aggravated by the fact that the conditions prevailing when the circuits are adjusted within the limits specified by the maintenance routines may depart considerably from the average. In addition to this, there are variations of considerable magnitude between individual circuits due to structural differences. In view of the fact that the variations over the whole frequency range are not the same, there is a material advantage in a compensator which adjusts the gain of each detector independently, a feature which could not be secured with a pilot-channel regulator.

Level Compensator

The level compensator,[23] shown diagrammatically in heavy lines in Fig. 6, may be considered as functionally divided into two parts, one of which is in series with the grid of the detector tube and the other of which is connected to the armature of the receiving relay. The first of these will be referred to as the *grid-bias circuit* and the second as the *compensator-relay circuit.*

The grid-bias circuit consists essentially of a condenser C shunted by a high resistance R_c, in series with a biasing battery E_0 of fixed voltage, the secondary of the interstage transformer T, and the grid-filament terminals of the detector tube V. This arrangement functions to keep the effective grid-filament voltage due to the signals nearly constant, irrespective of their magnitude, by setting up a voltage on the condenser which adds algebraically to the grid-bias battery and whose magnitude

* By a multi-section telegraph circuit is meant a connection made up of 2 or more telegraph lines in tandem with mechanical repetition between them.

is automatically adjusted to be proportional to that of the incoming signals.

At any instant the actual voltage between filament and grid is therefore equal to the algebraic sum of (1) the fixed bias voltage E_0;

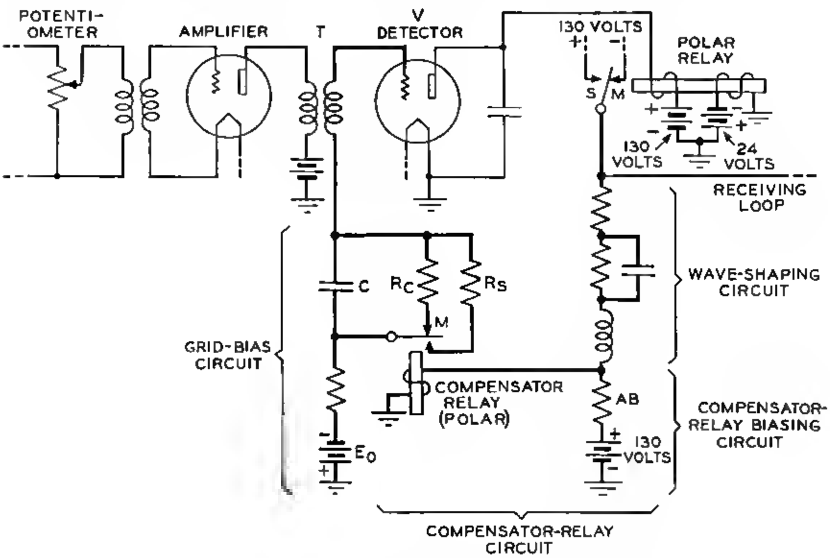

Fig. 6—Schematic diagram of level compensator.

(2) the voltage due to the charge on the condenser C; (3) the signal voltage across the secondary of the interstage transformer T; and (4) the drop in voltage across the transformer. By making the detector sensitivity sufficiently great, the signal voltage is caused to overcome the opposing negative bias during a portion of each positive half of the carrier cycles composing a marking pulse, so that a net positive voltage is periodically impressed on the grid causing a flow of current between it and the filament and consequently through the resistance R_c and the condenser C in parallel.

The resulting voltage across condenser C is in the same direction as that of the fixed grid battery E_0 and adds thereto. The condenser voltage is determined by the amplitude of the received carrier current, increasing with increased input level and decreasing with decreased input level. By a proper selection of the constants of the circuit, the desired compensation action may be obtained. This action will be such that the change in voltage across the condenser will always, within the effective range of compensation, produce the proper negative grid voltage for unbiased reception of telegraph signals by the

receiving relay. A quantitative discussion of the operation of the compensator is given in the Appendix.

In order that the voltage across the condenser may not decrease during spacing signals, an auxiliary polar relay, called the compensator relay, is provided which derives its operating current from the armature of the receiving relay and serves to disconnect the resistance R_c during spacing signals. As discussed in the appendix, the unbiased operation of the compensator relay would cause a noticeable decrease in the condenser voltage during the rapid transmission of signals, because the wave shape of the signals impressed on the grid circuit of the detector tube is not square but considerably rounded. In other words, there is a portion of a marking signal during which the receiving relay is operated to marking but the grid is non-conducting. Hence more charge would leak from the condenser during the time the resistance is connected across the condenser than would be replaced by rectification. To prevent this, the compensator relay bridges the discharge resistance R_c around condenser C for a period of time which is shorter than that during which the receiving relay is on its marking contact. The amount by which the compensator condenser must be biased depends on the signaling speed and other factors. It is determined by observing the "drift" in bias suffered by reversals when these are suddenly switched on after a long marking interval.

The operation of the level compensator will be more readily understood by referring to Fig. 7, which shows diagrammatically the manner in which received impulses of different magnitudes are made to operate the receiving relay for equal time intervals. In this diagram, the positive halves of the envelopes of three received marking impulses * of different amplitudes are shown in relation to the grid-voltage plate-current characteristic of the detector tube. For normal input level the sensitivity of the detector is made sufficiently great so that the amplitude of the impulse which is impressed on the interstage transformer is of the magnitude shown at N. The envelope of the received carrier current is symmetrical about the line E_N, which is located at the net value of grid biasing voltage due to the battery voltage E_0 and the grid condenser voltage e_c. The latter voltage, as previously noted, is produced in the grid circuit by rectification of that part of the received carrier current which lies on the positive side of the zero grid-voltage axis OO. By properly adjusting the bias of the receiving relay the latter may be made to operate at a value AA which is one-half the crest value of the envelope. Signals having amplitude N will thus be repeated unbiased by the receiving relay, since the ascending and de-

* In practice such pulses would usually reach the steady state.

scending curves bounding the envelope represent identical time sequences of events.

If the level increases so that the amplitude of the received signals has a value indicated by curve H, a much larger part of the signal current momentarily flows through the grid-filament space and is rectified, thereby increasing the charge on the condenser in such a

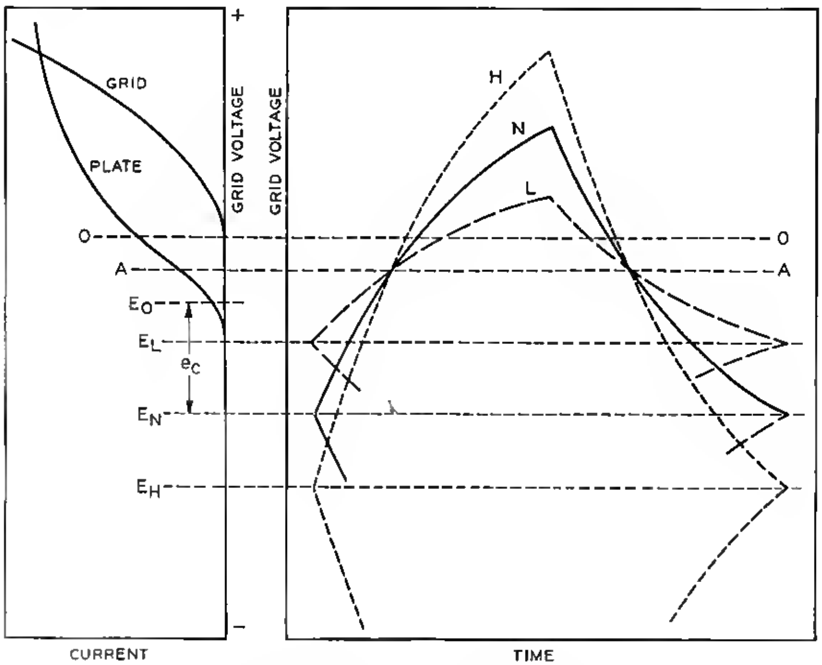

Fig. 7—Principle of level-compensator action.

way as to increase the negative bias of the grid and shift the signal bodily towards the negative side of OO. This shift continues until the total effective grid voltage has reached a point at which the rectified current is just sufficient to compensate for the increased discharge through resistance R_c due to the higher voltage across the condenser. The system is then in equilibrium at the new input level. If the constants of the circuit have been properly chosen, the new grid voltage E_H will be such that the middle of the positive envelope of the received signal again passes through the line AA, thereby giving unbiased signal reception.

The corresponding condition for an input level below normal is shown by curve L.

The condenser is the essential element of the compensator, and it is, of course, able to accumulate a charge in the absence of the resistance R_c; the only function of the latter being to dissipate this charge quickly when the input level drops. If there were only a resistance and no condenser there would be a simple rounding off of that part of the positive crests of the carrier waves which cause grid current to flow but no transfer of the operating axes as a whole to new bias values, such as E_L, E_N and E_H in Fig. 7.

Before leaving Fig. 7, it may be interesting to note parenthetically that a signal with large bias, such as H is much more immune to distortion due to changes in its own magnitude, or variations in relay bias, than a signal such as L. This can readily be seen if we imagine the line AA, which corresponds to the operating point of the receiving relay, to be moved up or down and note the relative lateral displacement of the intersections on these two envelopes. Another advantage of the stronger signal is that the rate of change of energy at the moment when the relay operates is much greater, insuring a more positive operation of its armature. The concave character of the detector characteristic is also favorable to securing a desirably shaped pulse for relay operation. Advantage was taken of these wave shaping possibilities in the design of detectors antedating the use of the level compensator to minimize the effect of circuit and battery variations.

In the absence of resistance R_s, Fig. 6, there would be a tendency during a long spacing interval for leakage in the wiring connected to the grid, to reduce the grid bias to ground potential. Before such discharge had gone very far, however, the receiving relay would close and recharge the condenser. This would give rise to periodic operation or *pulsing* of the relays. The purpose of R_s is to prevent this undesirable effect by making the negative bias voltage approximately equal to E_0 during long spaces. Since this resistance is large compared to R_c, it has a negligible effect during the reception of signals.

Where a circuit is exposed to transient additions of energy from external sources such as lightning, the operation of the level compensator may be stabilized by bridging a large capacitance in series with a resistance around condenser C.

Sending Circuit

In the voice-frequency telegraph system the spacing signals are produced at the transmitting end by short circuiting that portion of the circuit which supplies the sending filter with power, and the marking signals by allowing the current from the generator to flow through freely. This operation is performed by the sending relay.

Experience has shown that owing to the small a-c. voltages involved, there is a tendency for the contacts of the sending relay to increase in resistance, sometimes reaching a value as high as 1,000 ohms or more. In view of the low-impedance of the circuit originally used, this caused considerable residual current to flow during spacing intervals. In order to remedy this condition, the sending relay circuit was modified to the form shown in Fig. 8, in which an auto-transformer is so con-

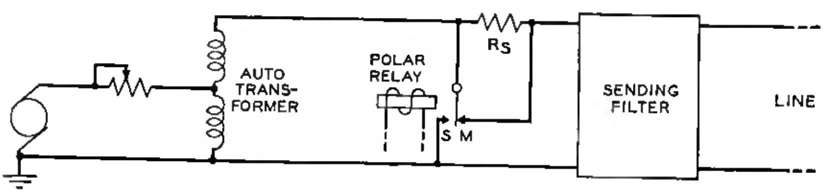

Fig. 8—Relay sending-circuit.

nected as to give a high impedance looking towards the generator, while R_s, which is of the order of 50,000 ohms, provides a correspondingly high resistance towards the output. The sending filter input is suitably padded to insure a satisfactory termination. It will be evident that with this arrangement the contact resistances in both the spacing and marking positions may vary considerably without seriously affecting the transmitting efficiency. Another advantage of R_s is that it eliminates the bias due to the transit time of the sending-relay armature, which may therefore be increased, and need not be kept within such precise limits: a matter of considerable convenience where demountable relays are used.

A trial has also been made of various schemes using varistors (copper-oxide rectifier-elements) to control the flow of carrier current by means of the changes in voltage in the loop circuit, thus dispensing with sending relays of the electromagnetic type. Figure 9*A* shows an arrangement which has been in actual operation for a number of years at several central offices and has given satisfaction. The loop circuit is provided with two equal apex resistances *RR*; hence when the key is closed the point x is positive relative to y regardless of the position of the receiving relay. This follows from the fact that the current through the loop is twice that through the loop-balancing resistance. On the other hand, if the receiving relay is on its marking contact, opening the loop key reverses the relative voltage between points x and y so that x becomes negative relative to y. In other words, polar signals are impressed between points x and y as a result of the transmission of signals in the loop. The a-c. part of the circuit contains a

bridge-like arrangement between the carrier source and the sending filter, which is balanced at all times with respect to the d-c. pulses so that these do not tend to be propagated into the line or towards the generator. When x is positive relative to y, rectifier elements a_1 and a_2

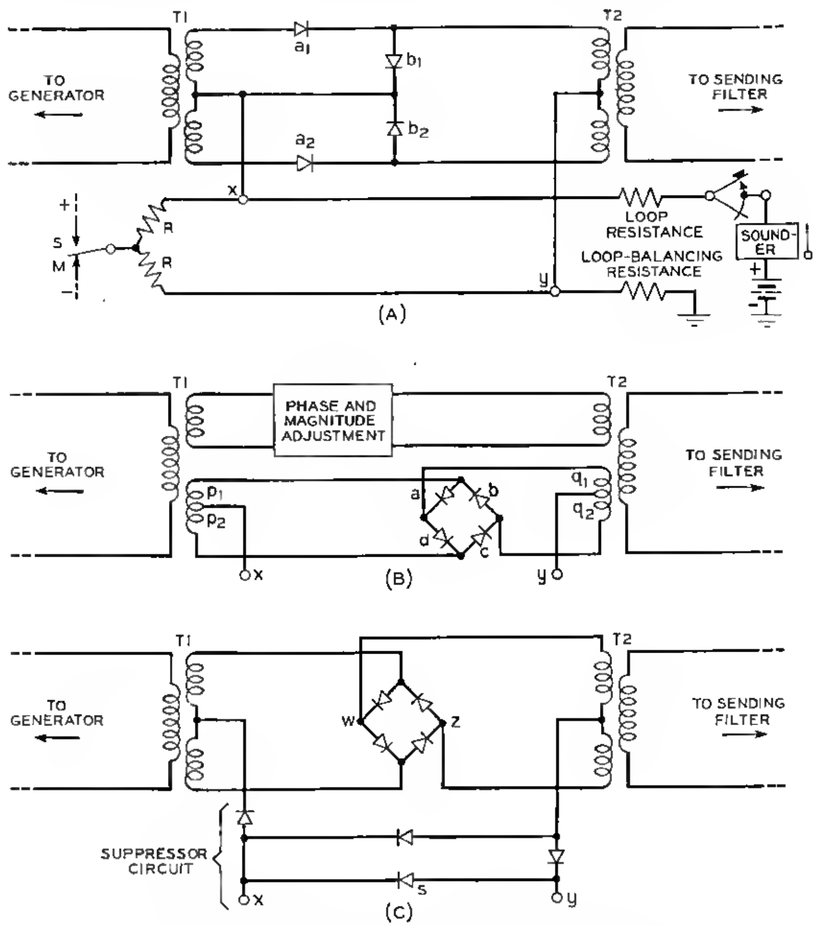

Fig. 9—Varistor sending-circuits. *A*. Series-parallel arrangement. *B*. Phase inverter. *C*. Non-polar arrangement.

are conducting while b_1 and b_2 are non-conducting. This allows a free path for the carrier between transformers T_1 and T_2 and thus from the generator to the sending filter. If, however, point x is negative relative to y, a_1 and a_2 acquire a high resistance, thereby greatly impeding the passage of current between T_1 and T_2, while b_1 and b_2 become conducting and effectively shunt the primary of T_2.

Alternative arrangements have also been tried. Two of these, which were used in actual installations, are shown in Figs. 9*B* and 9*C*. In both cases, the loop arrangement is the same as in Fig. 9*A*. The circuit of Fig. 9*B* consists of two parallel paths between generator and sending filter, one of which impresses a steady a-c. voltage on transformer T_2 while the second path serves to impress a second a-c. voltage of the same magnitude at the same point, but this latter voltage may be either in phase aiding or in phase opposing to the first, depending on the polarity of the d-c. voltage impressed through the varistor bridge. Thus it will readily be seen that if x is positive relative to y, elements a and c are conducting, while b and d are not. Transmission of the carrier then takes place around the path p_1, q_1, q_2, p_2, and the voltages from the two parallel circuits are additive in T_2. If, however, x is negative relative to y, the conducting condition of the varistor elements is reversed so that the carrier path becomes p_1, q_2, q_1, p_2, and the net voltage impressed on the primary of T_2 is zero.

The direct-transmission branch contains a phase and magnitude adjustment network to permit exact neutralization of the carrier voltage for the spacing condition.

Figure 9*C* is much like Fig. 9*B* except that the direct-transmission branch is omitted and a "suppressor circuit" is added, which may be thought of as changing the signals impressed on the varistor bridge from polar to neutral. This is done by inserting element s, which equalizes the voltage between points x and y whenever y is positive with respect to x. This effect is further enhanced by adding other series and shunt elements as shown. The bridge conditions for marking are the same as in Fig. 9*B*, while for spacing, all the elements are normal and alike so that the bridge is balanced for a-c. as well as for d-c.; thus no voltage appears between points w and z, and the carrier is suppressed.

While all these schemes involve balance between groups of varistors, recent advances in design have made it possible to fulfill this requirement to the desired extent and to maintain it over long periods of time.

The limited use to which varistor sending circuits have been put in the telegraph plant of the Bell System is not due to unsatisfactory operation in their present applications, but rather because they have imposed certain operating limitations on recently developed arrangements for interconnecting telegraph circuits.

Grid Bias

The fixed grid bias required by the level compensator exceeds the filament battery voltage, hence the latter cannot be used as a bias source and recourse is had to the negative 130-volt telegraph battery.

It follows that any variations in the latter will cause signal bias. To minimize this effect, several schemes have been used to stabilize the voltage applied to the level compensator. One of these is shown in Fig. 10*A*. In this arrangement the 130-volt battery discharges through

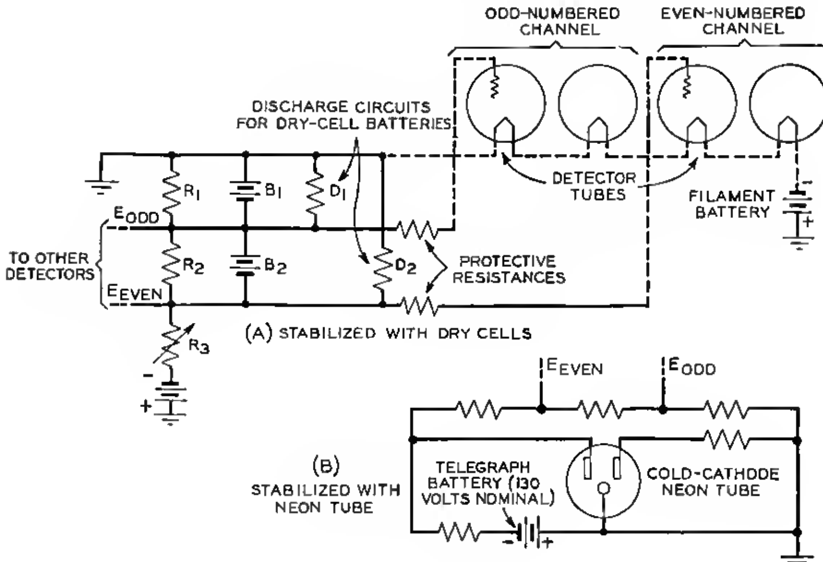

Fig. 10—Grid-bias supply circuits.

a series of resistances R_1, R_2 and R_3 so proportioned as to provide suitable taps giving the required bias when this battery is at its average voltage. Inasmuch as the filament circuits of two detectors are in series, two different voltages to ground are required. Dry cell batteries B_1 and B_2 are bridged between the taps which provide the desired biases and ground, of such values that they would give the proper voltages in the absence of the telegraph battery. These dry cells insure constant bias voltages; they supply no current when the telegraph battery is at its average value; discharge when it is low, and charge when it is high. Resistance R_3 is sufficiently large so that these charging and discharging currents are kept down to very small values and the life of the cells is consequently long. Since the bias batteries are part of a rectifying circuit there is a tendency for the signal current passing from grid to filament to charge the dry cells. To compensate for this, adjustable discharge circuits D_1 and D_2 are bridged respectively across the two grid-bias taps and ground in the manner shown, and their resistances are varied according to the number of detectors deriving their bias from this source.

A second method for securing a stable grid-bias voltage is shown in Fig. 10*B*. Here, advantage is taken of the fact that the voltage required to maintain discharge in a cold-cathode neon-tube is constant, by bridging such a tube across the negative 130-volt telegraph battery in series with a resistance. The desired voltages for the even and odd numbered detectors are then derived by tapping off at suitable points on a second resistance which is connected across the neon tube.

Interference

Interference in a particular channel may manifest itself either by the presence of current when none is intended or by a diminution of the signal current during a marking condition. The former is called *spacing interference*, and tends to change spacing units to marking units; the latter is termed *marking interference*, since it is observed during marking units, tending to change them to spaces.

The principal sources of spacing interference are:

1. Unsuppressed carrier.
2. Noise, lightning, etc.
3. Infiltration from adjacent channels.
4. Modulation products.

For marking interference, these are:

1. Crowding (Saturation effects).
2. Out-of-phase parasitic currents.

Parasitic currents (noise, modulation, etc.) are usually not an important source of marking interference, as their phase relative to that of the carrier forming the signal must fall within a rather narrow range to be effective.

If there exists some unsuppressed carrier during spacing intervals which is due to the design of the sending circuit, it will be fixed in value and may therefore be taken care of in the initial adjustments of the receiving circuit. All the other effects are of a chance character, being for the most part dependent on the transmission circumstances on associated channels or circuits. These effects, therefore, lead to fortuitous distortion.

The effectiveness of all forms of interference is dependent upon the ratio of their magnitudes to that of the signals with which they interfere. On the other hand, the absolute magnitude of the greater part of this interference depends upon the signal level. To establish a balance between these two tendencies, the telegraph power per channel which is transmitted over the circuit is selected so as to minimize the

effects of interference on telegraph signals and at the same time cause as little disturbance as possible to associated telegraph or telephone circuits. In the Bell System, the four-wire cable circuits used for telegraph purposes are for the most part devoted to this use exclusively and are organized with terminal repeater gains adapted for this special service. In the case of open-wire carrier-telephone circuits, on the other hand, the overall gain from modulator input to demodulator output is fixed by the telephone requirements, and the telegraph must be adapted thereto. The power per telegraph channel in dbm.* now used on cable and open-wire circuits is shown in Fig. 1 at various points.

The effect of changing the power on the line is illustrated qualitatively in Fig. 11, in which the variations of the received current with increasing transmitted current are sketched diagrammatically for various operating circumstances. By nominal power (*a*), is meant the power which would be received if transmission took place over a linear network having a fixed gain equal to the nominal gain of the circuit. Owing principally to the reduction of repeater gain which takes place with increasing load, the current actually received with all channels marking, is less than this (*c*). If only one channel is marking, some intermediate values (*b*) will be obtained of course, while if, as in the case of regular operation, some of the channels are spacing and others marking, still other values (c') will result. This saturation effect is sometimes called "crowding."

One of the contributions to spacing interference consists of ambient noise due to the combined crosstalk from all the other circuits in the cable and to external induction. This current is represented by curve *e*, which is shown as independent of the power transmitted; this corresponds to the situation existing where telegraph is a small part of the total traffic in the cable under consideration, for evidently if the power were increased on all the circuits the noise power would increase almost proportionally.

A more serious source of spacing interference consists of parasitic currents due to third-order modulation products arising directly or indirectly from the interaction of the several channels of the same system when passing through the non-linear elements of the circuit. Second-order modulation products are taken care of quite effectively by the receiving filters, due to the fact that the carriers are odd harmonics of 85 cycles, while these products being even harmonics thereof fall midway between channel frequencies. Since the attenuation of the receiving filters in the frequency range occupied by neighboring

* The symbol dbm. as used in this paper may be read "db referred to 1 milliwatt." It is intended to denote the ratio expressed in db of the power under consideration to 1 milliwatt; e.g., − 6 dbm. = .2512 milliwatt.

channels is finite, some infiltration of undesired frequencies takes place. Thus if a given channel is spacing and the adjacent ones marking, some small fraction of the flanking carriers will find their way into the idle

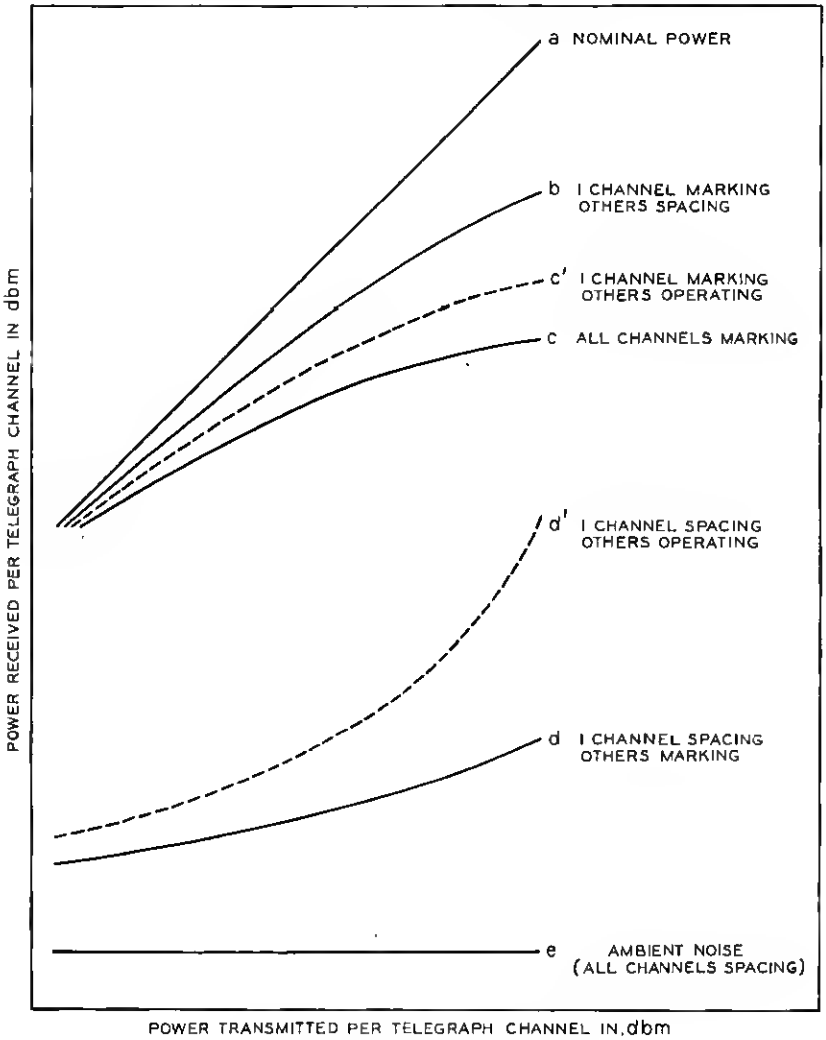

Fig. 11—Interference in cable circuits.

channel. Furthermore, if a channel is in operation, the sending filter does not completely suppress the sideband components lying outside the band assigned to it, and these pass freely through the receiving filter of nearby channels. Unlike modulation, the effectiveness of

filter action does not depend, to any large extent, upon the amount of power per channel, since the ratio of the disturbing currents to the signal remains approximately constant. Finally, such residual carrier as exists during spacing intervals may be variable in amount due to changes in the resistance of the sending relay contacts. If the power levels are increased sufficiently the total spacing interference will usually become due preponderantly to the modulation effects and hence a function of total power on the line, as indicated in curves d and d'.

In order to estimate the quality of transmission to be expected from circuits in view of these various interfering factors, it is desirable to establish the following two definitions:

> The signal-to-interference ratio * of a circuit is the ratio, expressed in db, of the normal marking current plus the interference, to the interference alone.
>
> The marking interference is the ratio, expressed in db, of the normal marking current alone, to the marking current plus the interference.

A variety of results may be obtained under these definitions depending upon the methods of observation: it is customary, therefore, to adopt the following practical specifications:

> *Signal-to-interference Ratio:* The change in sensitivity, expressed in db, required in the receiving circuit of a given channel, all other channels being in a marking condition, to just cause the armature of the receiving relay to go to its marking contact; first, with steady marking current transmitted over the channel under test, and second, with the channel under test opened at the sending end. It is understood that the currents are turned on and off by operating the sending relays and moreover that the receiving relay operates on one half the steady marking current. (E.g., no interference $= \infty$ db; complete failure $= 6$ db, approximately.)
>
> *Marking Interference:* The change in sensitivity, expressed in db, required in the receiving circuit of a given channel to just cause the armature of the receiving relay to go to its spacing contact; first, with steady marking current transmitted over the channel under test only, and second, with the interference added thereto. (E.g., no interference $= 0$ db; complete failure $= 6$ db, approximately.)

While the above method for measuring spacing interference is the one used in practice owing to the ease with which it can be applied,

* More precisely the signal to spacing-interference ratio.

a more significant characteristic is the signal-to-interference ratio obtained by observing the aforesaid change in receiving-circuit sensitivity required to operate the receiving relay in a given channel, as we go from a marking to a spacing condition in that channel with all other channels transmitting uncoordinated signals. This is not only a more practical consideration but a more severe condition, as indicated by curve d' in Fig. 11.

Carrier telegraphy, as here considered, is a marginal system of operation in which the current received for a marking condition corresponds on the average to that shown by curve c', while that for a spacing condition is the one represented by d'. The difference between these two characteristics is not all available for operation, however, since the receiving circuit must be made sufficiently sensitive to operate when the marking current has risen to half its final value, thus bringing the threshold of operation 6 db closer to the spacing interference. From these considerations it follows that the actual *operating margin* is an essentially variable quantity whose approximate value is less by about 6 db than the signal-to-interference ratio measured as specified above, since the indicated procedure takes account of marking as well as of spacing interference effects.

The following definitions are also useful in reporting and interpreting test results:

The *interference margins* of a circuit are the ratios, expressed in db, of the actual interference and the amount of this interference which will cause failure. More specifically:

(*a*) The spacing-interference margin is the increased sensitivity, expressed in db, required in the receiving circuit of a given channel adjusted to receive unbiased signals in the absence of interference, to just cause the receiving relay to close when interference alone is present (e.g., no interference $= \infty$ db; complete failure $= 0$ db).

(*b*) The marking-interference margin is the decrease in sensitivity, expressed in db, required in the receiving circuit of a given channel adjusted to receive unbiased signals in the absence of interference, to just cause the receiving relay to open when interference is added (e.g., no interference $= 6$ db, approximately; complete failure $= 0$ db).

Clearly the various effects which have been defined above, being of a variable and indeterminate character, contribute to the fortuitous distortion of signals. This is illustrated in Fig. 12, which shows what

may happen to a single dot. The extreme conditions of operation on the particular channel under consideration are those where all of the channels are marking or spacing. If they are all spacing, there is only noise and unsuppressed carrier, and the change in received current

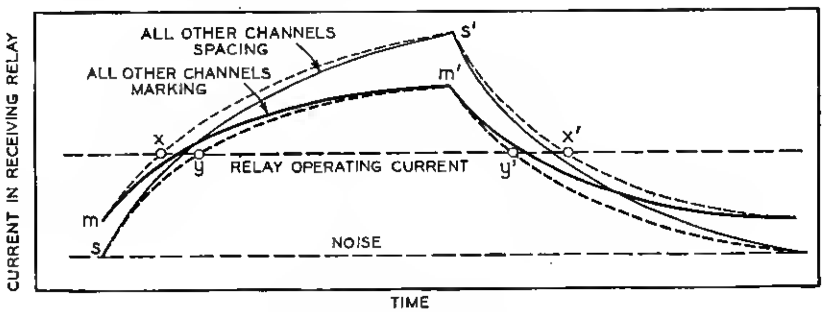

Fig. 12—Effect of interference on signal distortion.

when the one operating channel changes from space to mark is the vertical distance between points s and s', while when all the other channels are marking the change is from m to m'. The ratio of the currents corresponding to either of these pairs of points, when expressed in db, may be conveniently called the *marking-to-spacing ratio*. Practically, of course, the power over the line will be constantly and fortuitously varying, so that the actual arrival curves will lie somewhere between certain limiting values indicated by the dotted lines ms' and sm', giving rise to a range of fortuitous distortions which, if the receiving equipment was adjusted with all the other channels marking, will depend on the length of the extreme intervals xx' and yy'.

The results obtained in the course of experimental observations of some of the above quantities are given below. They were secured on a 700-mile H44 cable circuit of the type described at the beginning of this paper. In order to obtain uniform results, the output of each of the 17 repeaters in tandem in this circuit was adjusted to the same level, so that each output tube contributed about equally to the total modulation effects and a similar uniformity existed relative to the most heavily energized loading coils. In practice, the saturation effects would not be likely to exceed this, and generally would be somewhat less.

Figure 13*A* shows typically the effect on the received current of increasing the total power transmitted over the line when all channels are marking simultaneously. This phenomenon (which may be called crowding) is a measure of the intermodulation which is caused by the

circuit during normal operation, since the power transmitted over the circuit then varies fortuitously over a range of 10.8 db for a 12-channel circuit and 13.8 db for a 24-channel system, depending on the number of channels which happen to be marking simultaneously.

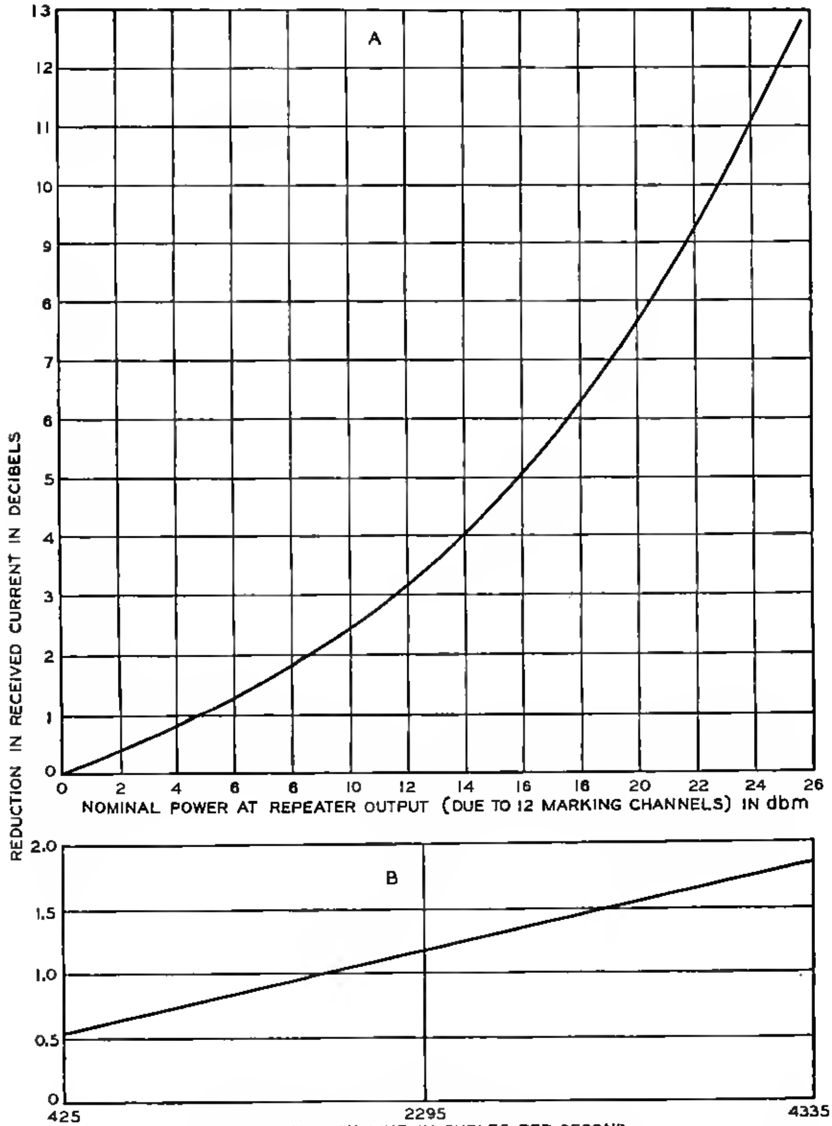

Fig. 13—Crowding. H44 circuits. *A*. Relative crowding vs. power. 12 channel system. Channel No. 5 (1105 cycles per second). *B*. Crowding vs. frequency. 24 channel system. Total power at repeater output increased from 2.2 to 9.2 dbm.

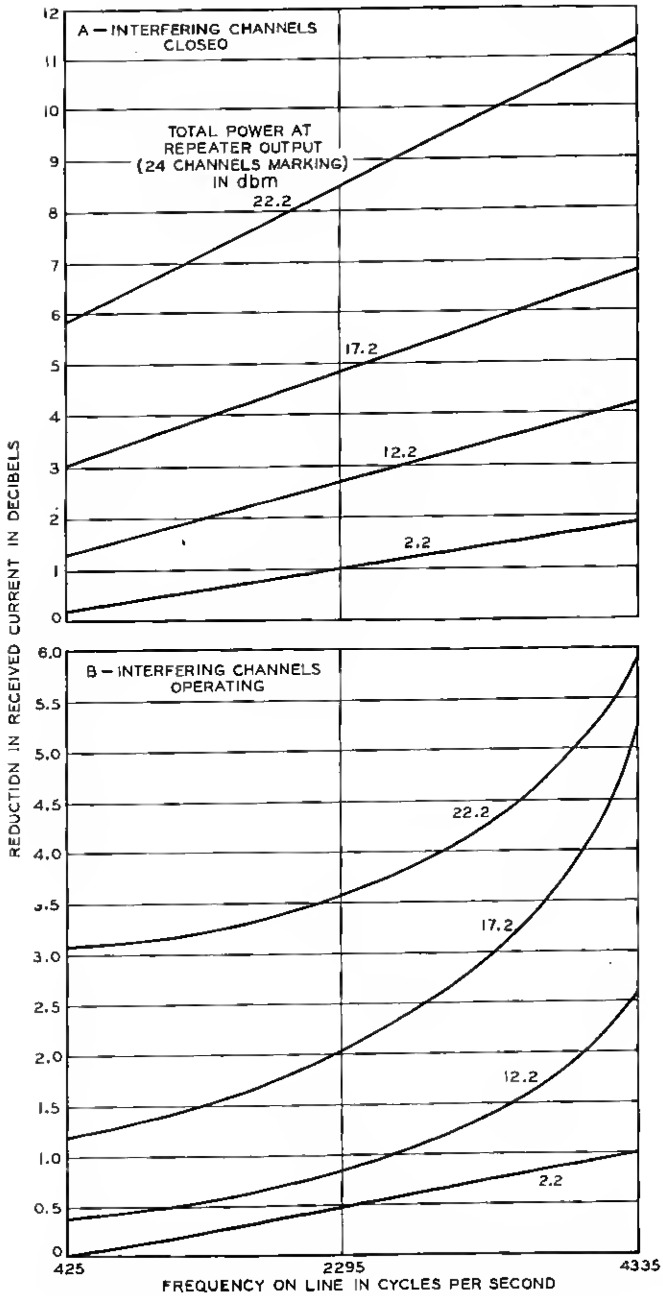

Fig. 14—Marking interference vs. frequency. H44 circuits. 24-channel system.

As will be seen by reference to Fig. 13*B* there is a marked frequency effect; the variations becoming greater for the higher frequency channels. This is particularly noticeable where there is a large number of channels operating simultaneously, as otherwise individual variations between channels tend to obscure the gradual trend.

Figure 14*A* shows the marking interference, expressed in db, due to changing from one channel marking to all channels marking for various changes in repeater output ranging from 2.2 to 22.2 dbm. and a frequency range extending from 425 to 4335 cycles.

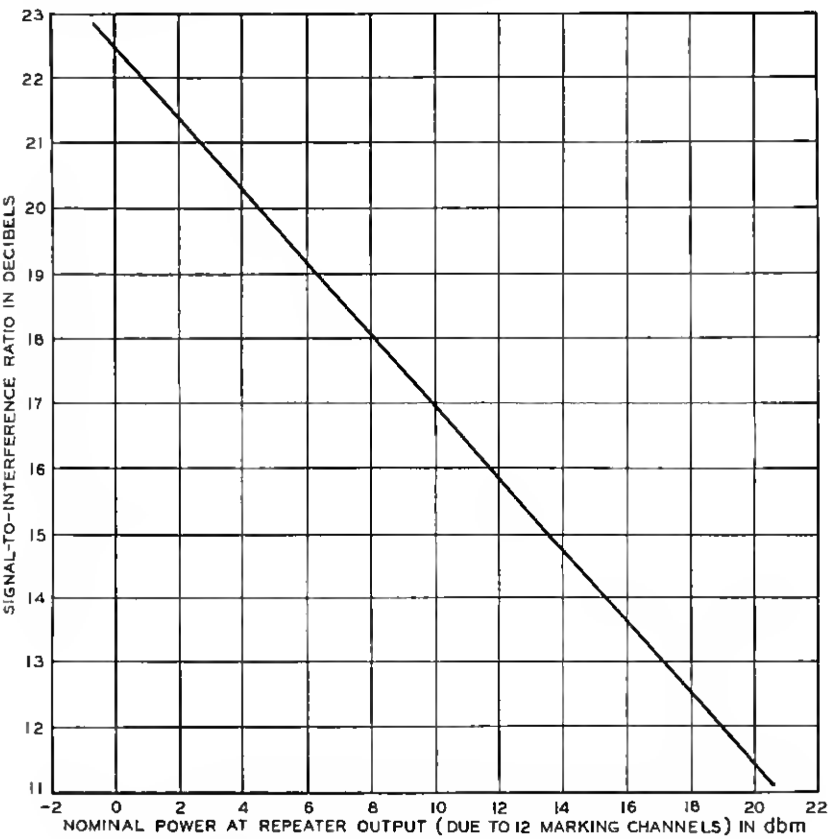

Fig. 15—Spacing interference. H44 circuits. Interfering channels operating. 12 channel system. Channel No. 5 (1105 cycles per second).

Figure 14*B* shows the reduction in received current which results on any given channel over the same range of conditions as Fig. 14*A* except that in this case the associated channels are transmitting uncoordinated reversals.

These interfering effects are subject to considerable variations from channel to channel in an irregular manner depending on repeater spacing, phase relations between the carrier sources, etc., so that the characteristics given in Figs. 13 and 14 must be interpreted as indicating average values and trends rather than specific amounts.

The erratic character of the results due to such fortuitous circumstances is particularly noticeable in spacing interference measurements made as a function of channel frequency, or in those relating to parasitic currents produced by steady currents in the remaining channels of the system. The general effect of repeater load on spacing interference is illustrated for a particular channel in Fig. 15. This refers to the case where the interference is caused by non-synchronized signals on the remaining channels.

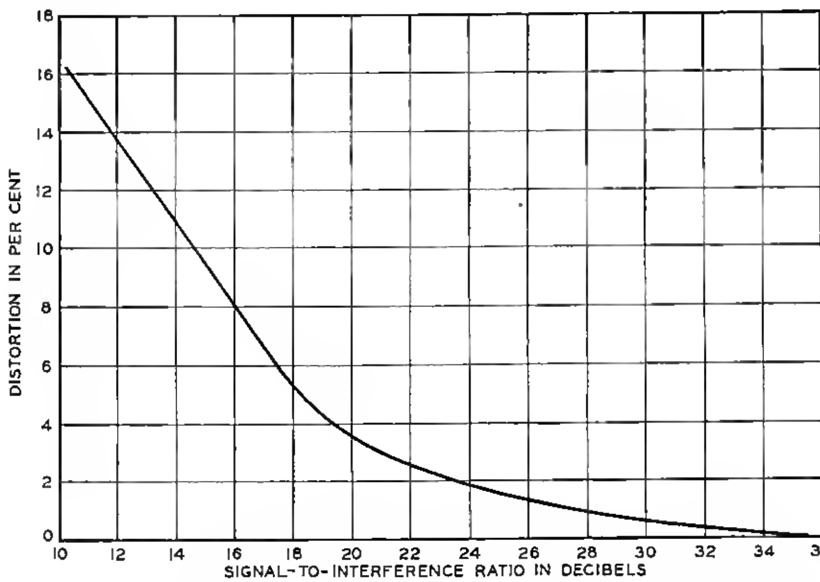

Fig. 16—Increase in signal distortion caused by spacing interference.

As far as the toll line itself is concerned, noise from other circuits is an almost negligible factor in the distortion of signals. It is of a highly fortuitous character and shows no definite trend with frequency except perhaps as it may be somewhat greater in the effective voice range, as modified, however, by variations in cross-talk efficiency with frequency.

The effect of spacing interference on telegraph distortion is given in Fig. 16, which shows that a residual current as small as 30 db below signaling begins to degrade transmission.

Operation Over Carrier Telephone Circuits

Where v-f. telegraph operates through the same repeaters as one or more telephone circuits, as in the case of carrier-telephone systems, a new form of variable interference arises due to the changing load conditions introduced by variations in voice volume. Where there are comparatively few telephone channels involved, as in the type C carrier-telephone system for instance, there is very little averaging and the voice peaks determine the repeater load which is effective in

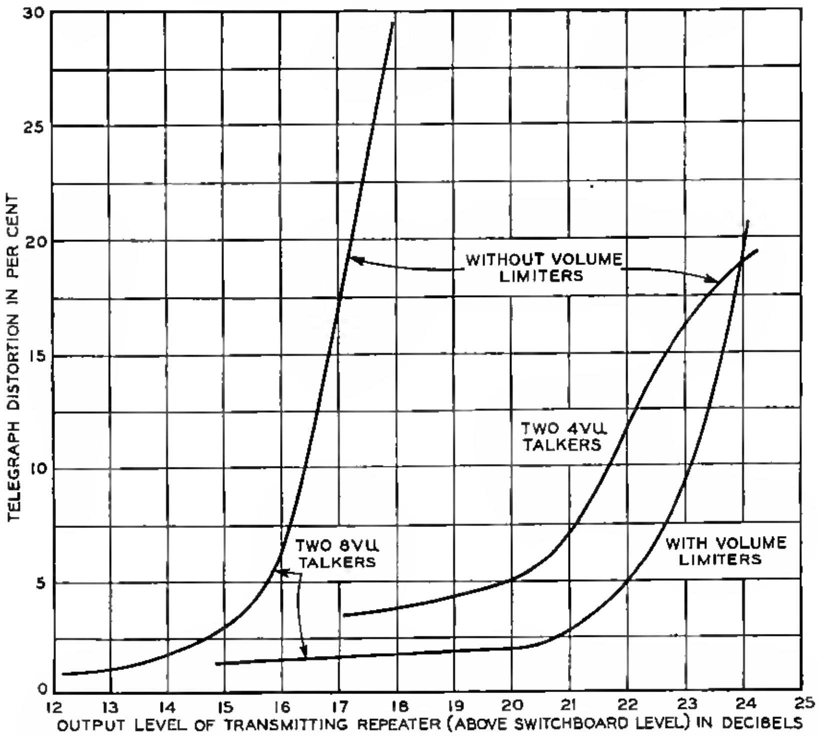

Fig. 17—Voice-frequency telegraph operated over an open-wire carrier-telephone circuit. Effect of associated telephone channels on telegraph distortion.

causing interference to telegraph. This interference is due in part to changes in net-loss of the circuit resulting from the non-linearity of amplification and in part to intermodulation between the various currents passing through the repeaters simultaneously. Figure 17 gives an example of the distortion produced in a telegraph circuit operating over one channel of a 3-channel telephone system when the other two are occupied by two equal-volume talkers. The marked

reduction in permissible repeater amplification as we change from two 4-vu to two 8-vu talkers is evident. This figure also shows that by the use of the volume limiters mentioned at the beginning of the paper, the repeater gains with the higher volume talkers may be made at least as great as for the lower volume. This makes it possible to use the present telephone circuits for carrier telegraph purposes without change.

Drainage

The occurrence of atmospheric disturbances, and particularly lightning, constitutes a potential hazard to the operation on open-wire circuits of a service as exacting as carrier telegraph. Where such circuits have been transposed for the operation of carrier telephone, the transverse or metallic-circuit effects due to lightning discharges in the neighborhood of the line are in general not serious, but the voltages generated to ground are very often of sufficient magnitude to cause a breakdown of the protectors. Since it has been found impracticable to devise protectors with such precise limits that they will operate at the same voltage and possess the same discharge characteristics, a transient transverse current is set up in such cases which may cause telegraph errors.

The remedy adopted consists in bridging drainage coils [24] across the line at all points where protectors are required, and in so connecting them that they will either prevent a breakdown of the protectors or assure simultaneous operation with equal discharge currents from either wire to ground.

In Fig. 18*A* the drainage coil is shown bridged directly across each end of the open-wire line between two sections of entrance cable. These coils consist of two carefully balanced windings with the mid-point grounded. They present a high impedance to voice or carrier currents transversely, but offer only a small resistance to ground for longitudinal currents compared with that across the adjacent protector blocks. The chief disadvantage of this method, which is called "direct drainage," is that it prevents the use of grounded telegraph and interferes with the testing of the line by means of direct current. To obviate this, the scheme shown in Fig. 18-*B* has been devised, which is termed "protector drainage." In this case, the drainage coil is connected to the line wires through protectors having a low breakdown-voltage. This combination is backed by high-voltage protectors to insure unimpeded discharge in case of large disturbances. With this arrangement the drainage coil does not come into operation unless there is a severe disturbance, and furthermore owing to the mutual inductance between the two halves of its windings it tends to cause

such discharge to occur at the same moment and be of equal magnitude from both wires of the pair to ground whenever it does operate.

Extensive tests and practical experience have shown that the above arrangements are quite effective, affording a reduction of about 95

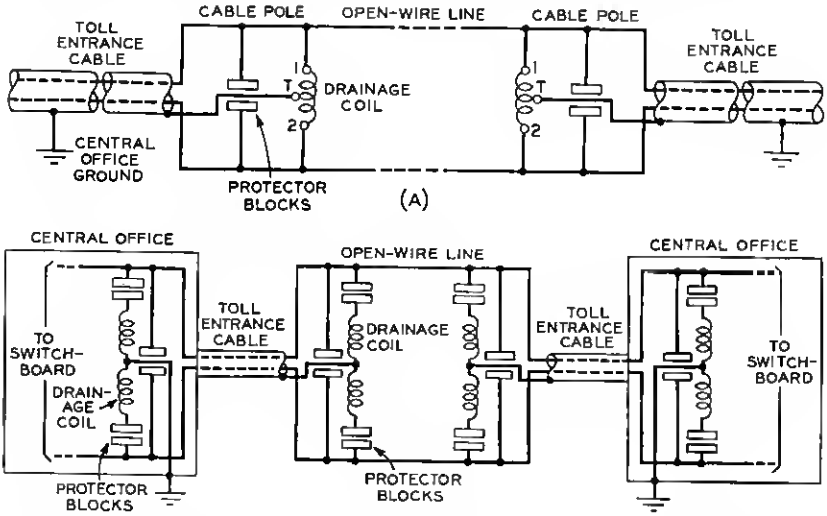

Fig. 18—Drainage arrangements. *A*. Direct drainage. *B*. Protector drainage.

per cent in the number of disturbances occurring on the line as well as in the number of errors in transmission resulting therefrom.

Carrier Supply

The inductor-alternator source for carrier frequencies used in the original installation has been retained except for the addition of two channel frequencies, and the substitution of improved means of speed (frequency) control. The first mechanical governor was soon superseded by a center-contact device which is much less erratic in operation.

The carrier frequency can be shifted over quite a few cycles from its correct value without affecting signal distortion appreciably but rapid speed variations have a more serious effect. Two methods have been used to overcome this difficulty. The first consists effectively in making the generator part of a system having great overall inertia, the second in subjecting it to very rigid control.

To secure the first end the VF generator is driven by a synchronous motor operated from the lighting circuit. This arrangement can, of course, be used only where the frequency of the commercial power is regulated within narrow limits. The required generator speed being

1700 r.p.m. a belt drive is used to reduce the motor speed of 1800 r.p.m. to the proper value; small adjustments in speed being provided by means of a *V* pulley having an adjustable diameter.

In order to insure continuity of operation in case of failure of the power supply the generator is also arranged to be driven by a d-c. motor equipped with a mechanical governor. This motor is supplied from the central office battery and is automatically switched thereto in case the voltage of the commercial power supply falls below a predetermined value.

In the second method the VF carrier-supply unit is governed by means of a vacuum-tube circuit whose output is controlled by frequency variations in the highest frequency channel, and the resulting d-c. current is applied to the motor field. The operation of this device, which has been described elsewhere,[25] may be briefly explained as

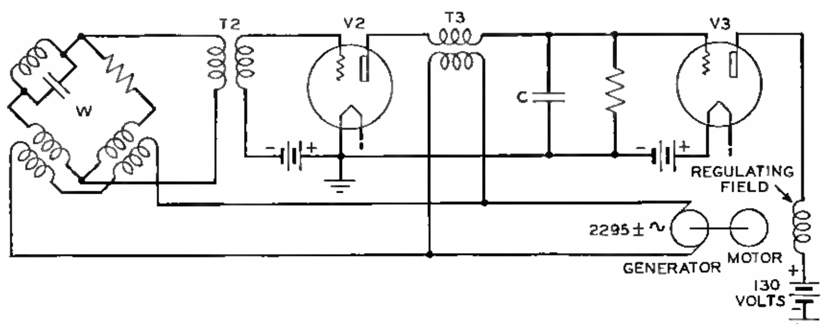

Fig. 19—Principle of tuned-circuit speed-regulator.

follows: It depends for accomplishing its purpose on producing variations in the strength of the current through an auxiliary regulating field associated with the motor which drives the multi-frequency generator. The essential features are shown in Fig. 19. The action is as follows: The voltage of channel 12 (2295 cycles) of the generator whose speed is to be controlled is applied simultaneously through a divided circuit to the input and output of tube V_2 which may be called the phase-detector tube. The plate voltage is applied directly through transformer T_3, there being no *B* battery in the ordinary sense. The grid voltage on the other hand is applied through the bridge *W*, one of the arms of which is an anti-resonant circuit tuned to 2295 cycles. The result is that the magnitude of the grid-filament voltage and its phase relative to the plate voltage are dependent on frequency. When the latter has its correct value the anti-resonant arm exactly balances the bridge, and the a-c. voltage across T_2 is nil. At higher frequencies

this circuit acts like a capacitance, while at lower frequencies it acts like an inductance. There is thus a rapid change in both the voltage and in the phase thereof across T_2 whenever there is a variation in frequency on either side of the specified value. The output current from V_2, combining with the current impressed directly through T_3, produces corresponding abrupt changes in the d-c. component of the resultant which in turn varies the bias of tube V_3 and hence the current through the regulating field of the motor.

In order to assure a rapid change in impedance with frequency, the anti-resonant circuit referred to above comprises a carefully shielded air-core coil having a very small resistance relative to its inductance.

The frequency indicator shown in Fig. 20*A* provides means for easily

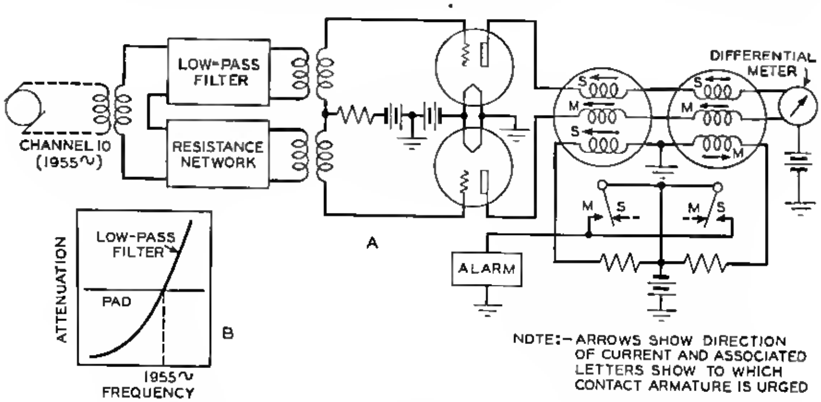

Fig. 20—Frequency indicator. *A*. Schematic diagram. *B*. Attenuation of two input-paths.

observing any departures of the carrier frequency from its nominal value, as well as an automatic maximum-minimum alarm to warn the attendant if these variations become excessive. Since all the carrier currents are derived from generator elements which are mounted on a common shaft, it is sufficient to observe the frequency of a single channel. Current from channel 10 (1955 cycles) is impressed simultaneously on two vacuum tube circuits which are identical except for the fact that there is a low-pass filter in the input of one while there is a simple pad in the input of the other. As indicated in Fig. 20-*B*, the loss through the pad is the same at all frequencies and equal to that of the filter when the generator speed is correct. If the frequency increases, the attenuation of the filter branch goes up; while if it decreases, its attenuation goes down; but in any case the loss through the pad remains constant, of course. The net resulting ampere-turns

tend to move one or the other relay armature to the opposite contact according as the frequency is high or low, and thereby ring the alarm. This resulting current also indicates the amount by which the frequency departs from its nominal value.

The frequency indicator may be used with either the mechanical governor or with the synchronous drive, but it is of little use with the vacuum tube tuned circuit control as the latter is too precise to register any indications.

The frequency indicator does not permit a very close adjustment of the mechanical governor nor does it provide a satisfactory check for the correctness of the frequency of the commercial power when a synchronous motor is used, so a stroboscopic method has been adopted as an ultimate standard of comparison. This stroboscope consists of a cylindrical target made up of three distinct peripheral rows of alternate black and white segments mounted on the end of the generator shaft. These segments may be viewed by means of a tuning fork fitted with overlapping metal plates attached to the ends of the tines. Slits cut in these plates lie opposite each other when the fork is at rest. When it is set vibrating, vision through the slits can therefore be established momentarily twice during each complete oscillation. By illuminating the target with a steady source of light the apparent direction of motion of the dots can thus be observed by looking through the slits. The middle row of segments on the target is so proportioned as to appear stationary if the speed is practically correct while the outer rows appear respectively stationary if the speed is approximately 1 per cent above or below the nominal value.

For offices where the frequency of the commercial supply is sufficiently stable, an additional and somewhat more convenient method for checking the speed has been made available. It consists of a special target mounted on the generator shaft, which is illuminated by a neon lamp associated with a wave-shaping circuit which makes the flashing time a very brief portion of each pulse of the 60-cycle current. In other words, the attendant in this case looks at the target constantly under intermittent illumination, while in the former case he views it intermittently under constant illumination.

Testing Facilities

While developments in carrier telegraph equipment have resulted in considerable economies, the ever increasing demand for service which is freer from errors and interruptions and is adaptable to circuits of greater length and complexity has tended to render the maintenance problem increasingly difficult and time consuming. Voice-frequency

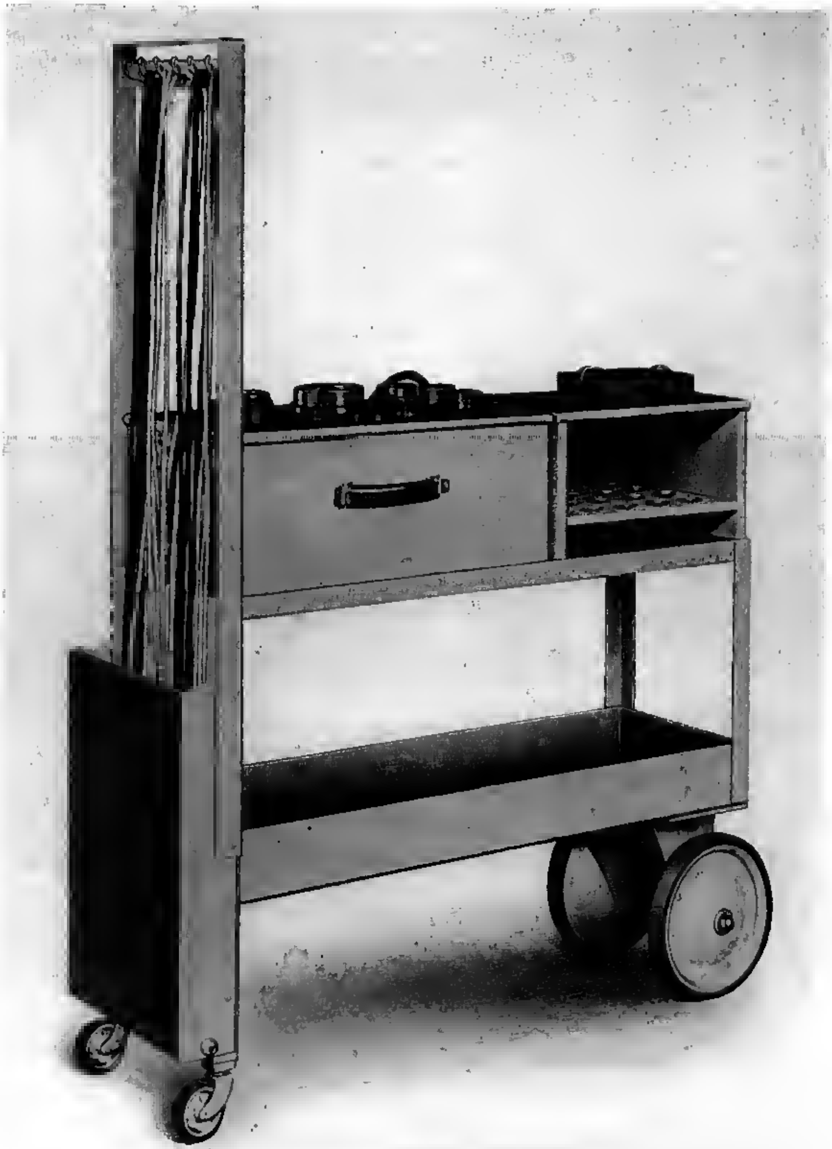

Fig. 21—Carrier-telegraph test set. General view.

telegraph circuits equipped with level compensators must be subjected to a series of specialized tests and adjustments whenever placed in service and at periodic intervals thereafter. To provide for this, a special testing set comprising in readily available form all the test equipment required for this purpose, has recently been introduced. It includes the following features:

1. Bias measuring circuit.
2. Filament-activity test-circuit and filament-current measuring circuit.
3. Drift measuring circuit.
4. Test amplifier.
5. Adjustable attenuator.

With this set all terminal tests may be made from one end of the circuit without the use of a line or external line-simulating repeater as

Fig. 22—Carrier-telegraph test set. Instrument panel.

was done in the past. It is mounted on a small wagon which may be wheeled into position adjacent to the terminals to be tested, then connected by means of a long cord and multiple contact plug to the necessary battery supplies, grounds, etc. The general appearance of the set is shown in Fig. 21, while a more detailed view of the face equipment may be obtained from Fig. 22.

The bias measuring circuit is shown in simplified form in Fig. 23. It uses a 215 type polar relay,[26] or its equivalent, with a meter connected in the armature circuit. This meter, which permits measuring to an accuracy better than 1 per cent, is specially designed to have the proper ballistic and damping characteristics to permit measuring dot

signals having a rate of 11 d.p.s. The reason for providing 11-cycle reversals is that experience has shown that these more nearly simulate miscellaneous teletypewriter signals, both with respect to bias and drift, than the higher speed reversals used in the past. An end scale

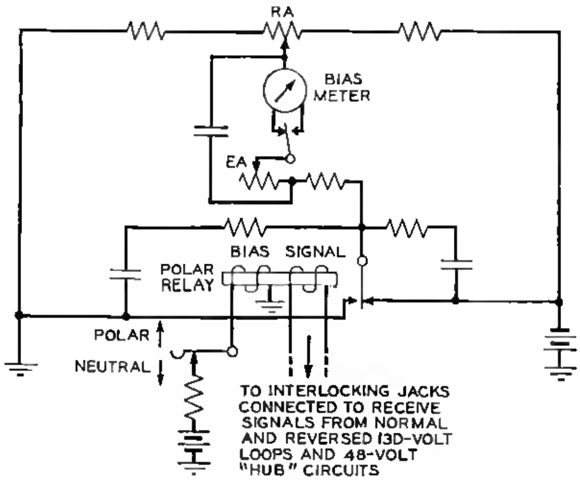

Fig. 23—Carrier-telegraph test set. Bias measuring circuit.

adjustment *EA* permits correction for battery variations, while a second adjustment *RA* allows for correcting any residual bias which may be present in the 215 type relay or in the dot signals used for the tests.

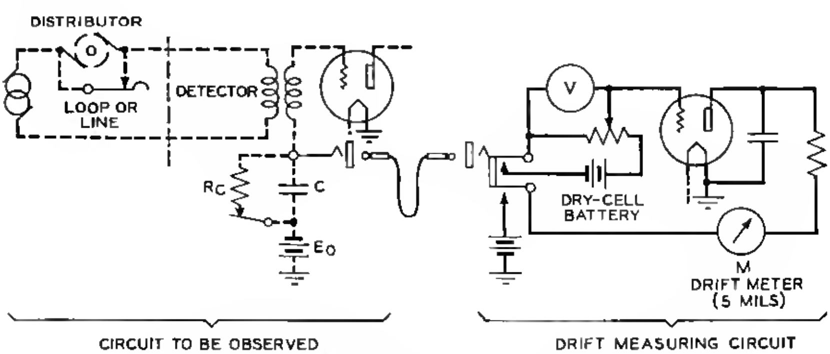

Fig. 24—Carrier-telegraph test set. Drift measuring circuit.

In order to observe and correct for the drift effect discussed previously, a special circuit is provided which is illustrated in Fig. 24. The skeletonized diagram of the carrier-terminal circuit to which it is applied, shown to the left in dotted lines, will help to understand the

function of this measuring device. The object is to observe the change in voltage experienced by the upper plate of the level compensator condenser when incoming signals are changed from steady marking to dots. The circuit provided for this purpose is essentially a vacuum-tube electrostatic voltmeter of the conventional type.

Acknowledgment

The advances in the art which have been described in the foregoing pages have taken place over a number of years and cover a considerable variety of subjects. Much of the material is to be found only in test reports and unpublished memoranda. Since such work is, of necessity, the product of the cooperation of many minds, it is impracticable in most cases to apportion credit equitably and the author must therefore confine himself to a general expression of indebtedness to his associates.

APPENDIX

LEVEL COMPENSATOR THEORY

The theory of the level compensator may best be considered in two stages, first taking the steady marking condition, and second the condition where signals are being received.

Steady Marking Condition

Figure 25*A* shows the essential elements involved when the steady current I_0 flows through the receiving relay. Figure 25*B* is the

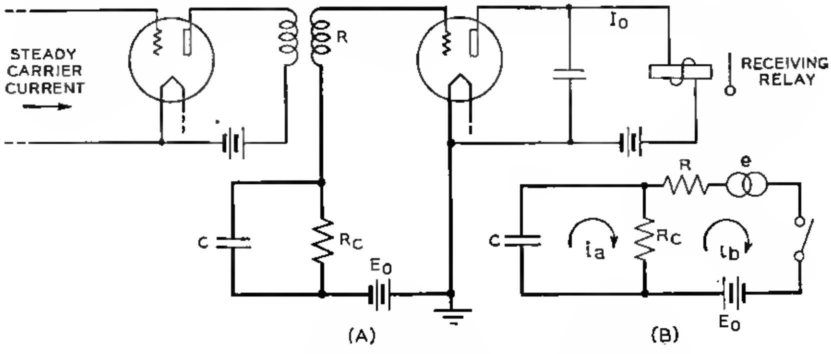

Fig. 25—Theory of level compensator. *A*. Simplified circuit. *B*. Equivalent circuit.

equivalent of the grid circuit shown in heavy lines on Fig. 25*A*, on the assumption that the grid-filament space is effectively a switch which turns the grid current on or off when the grid goes positive or negative,

respectively, and that the interstage transformer is perfect. The tube resistance which is effective during the conducting period may be included in R and considered constant, as it is relatively small compared to the other resistances involved.

In describing the principle of action of the level compensator, it has been pointed out that for proper compensation the point of relay operation AA (Fig. 7) should bisect the crest value of the signal pulse in each case. In this figure, the three envelopes shown correspond to very short signal pulses; if the signals were sufficiently long so that a steady marking condition were reached, as is usually the case, the crest of the signal would coincide with the peaks of the steady carrier wave, and AA would bisect its positive loops.

For long signals the condition for proper compensation is therefore that the relay will just operate at one-half the steady-state carrier voltage. This is true for all carrier voltages E which equal or exceed the value required to make the grid positive. In the particular case where E just fails to cause the condenser to charge, $E = -E_0$ and the relay operates when a value $-E_0/2$ is reached. For any other greater value of E it is necessary in addition to overcome the voltage due to the charge on the condenser before the relay will operate. The criterion for perfect compensation where signals are of sufficient duration so that the steady state is reached is therefore:

$$\frac{E}{2} + \frac{E_0}{2} - e_c = 0, \tag{1}$$

where E is the maximum value of the instantaneous steady state carrier voltage, and E, E_0 are arbitrarily taken with such polarities as to urge the mesh current i_a in the direction indicated in Fig. 25B, while e_c is negative because it opposes the current i_a which gives rise to it.

Substituting $e_c = Q/C$ in (1) we have

$$\frac{E}{2} = -\left(\frac{E_0}{2} - \frac{Q}{C}\right), \tag{1a}$$

where Q is the average charge existing on the condenser during a long mark for any particular value of E. The problem of compensation then resolves itself in adjusting the constants C, R, R_c, and E_0 so that relation (1a) will hold; in other words an expression for Q must be found in terms of these parameters. The problem is not susceptible of explicit solution, but expressions will be derived which are believed to clarify the operation of the compensator and permit computation.

Referring to Fig. 26 let A represent the positive halves of the open circuit voltage across the secondary of the interstage transformer due to the steadily impressed carrier; and B represent the instantaneous

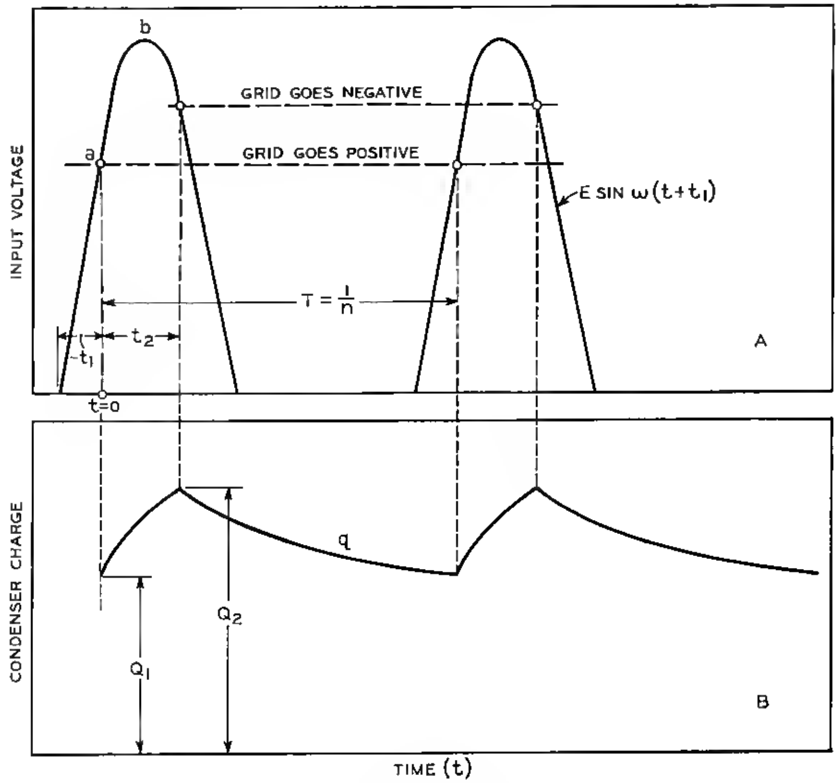

Fig. 26—Theory of level compensator. *A*. Carrier voltage. *B*. Condenser charge.

charge on the condenser. Reckoning time from the instant a when the grid goes positive, we have:

$$e = E \sin \omega(t + t_1), \tag{2}$$

where $\omega/2\pi$ is the carrier frequency.

Consider the instant at which $t = - t_1$: e is increasing through its zero value, the switch representing the grid-filament space (Fig. 25*B*) is open and the condenser is discharging through R_c. This state of affairs continues until e reaches a value which nullifies the condenser voltage plus the steady grid bias so that the voltage across the switch

is zero. At $t = 0$, the switch closes and current i_b starts to flow. If Q_1 is the charge on the condenser at $t = 0$,

$$\frac{Q_1}{C} = E \sin \omega t_1 + E_0. \tag{3}$$

The switch remains closed while e increases to its crest value at b and then decreases until, at time $t = t_2$, the grid goes negative. If Q_2 is the charge on the condenser at $t = t_2$

$$\frac{Q_2}{C} = E \sin \omega(t_1 + t_2) + E_0. \tag{4}$$

The switch now opens, and the condenser discharges through R_c until the switch closes once more at $t = T$ to begin another cycle, T being the carrier period $2\pi/\omega$. During this interval the charge on the condenser is given by

$$q = Q_2 \epsilon^{-(t-t_2)/CR_c}. \tag{5}$$

In order that steady-state conditions may prevail, that is, in order that every cycle be the same as its predecessor, q must again equal Q_1 when $t = T$. Hence

$$Q_1 = Q_2 \epsilon^{-(T-t_2)/CR_c}$$

or, setting

$$D = \epsilon^{-(T-t_2)/CR_c}$$

$$Q_1 = Q_2 D. \tag{6}$$

In connection with equation (1a) it has been pointed out that what is sought is an expression for the average charge Q in terms of the parameters. Referring to Fig. 26B, it will be seen that this average lies somewhere between Q_1 and Q_2, but since Q_1 is very large compared with $Q_2 - Q_1$, we may take either Q_1 or Q_2 as equal to the average charge Q in (1a), when considering the effect of bias on the grid of the detector tube in producing compensator action. For the sake of definiteness, let:

$$\frac{E}{2} = -\left(\frac{E_0}{2} - \frac{Q_1}{C}\right). \tag{1b}$$

Equations 3, 4 and 6 contain the five unknowns E, Q_1, Q_2, t_1, t_2; hence one more relation must be established before we can get the desired formulation between E and Q_1. The circuit equations for Fig. 25B when the switch is closed (charging period) furnish the required relation. Thus:

$$\frac{q}{C} + R_c(i_a - i_b) = 0$$

$$(R + R_c)i_b - R_c i_a = E \sin \omega(t + t_1) + E_0.$$

Eliminating i_b, setting $i_a = \frac{dq}{dt}$ and $\alpha = (R + R_c)/RR_cC$ we have

$$\frac{dq}{dt} + \alpha q = \frac{E}{R} \sin \omega(t + t_1) + \frac{E_0}{R},$$

whence

$$q = EPF(t + t_1) + \frac{E_0}{\alpha R} + A\epsilon^{-\alpha t}, \tag{7}$$

where A is the constant of integration and

$$P = 1/R(\alpha^2 + \omega^2), \qquad F(x) = \alpha \sin \omega x - \omega \cos \omega x.$$

Since q obeys (7) from $t = 0$ until $t = t_2$, we have for the initial and final charges during the charging portion of the cycle:

$$Q_1 = EPF(t_1) + \frac{E_0}{\alpha R} + A$$

$$Q_2 = EPF(t_1 + t_2) + \frac{E_0}{\alpha R} + A\epsilon^{-\alpha t_2}.$$

Eliminating A

$$Q_1 - Q_2\epsilon^{\alpha t_2} = EP\left[F(t_1) - \epsilon^{\alpha t_2}F(t_1 + t_2) \right] + \frac{E_0}{\alpha R}\left[1 - \epsilon^{\alpha t_2} \right], \tag{8}$$

which is the additional equation required.

It now merely remains to eliminate some of the unknowns. To this end we first eliminate Q_1 and Q_2 from (3) and (4) by means of (6) and, solving for E, obtain

$$E = -E_0 \frac{D - 1}{D \sin \omega(t_1 + t_2) - \sin \omega t_1}. \tag{9}$$

A second expression for E involving the same variables is next obtained by replacing Q_1 and Q_2 in (8) by their values as given by (3) and (4). Equating these two expressions for E leads to:

$$\tan \omega t_1 = \frac{G_2 + G_3 \sin \omega t_2 - BG_2 \cos \omega t_2}{G_1 - G_3 \cos \omega t_2 - BG_2 \sin \omega t_2}, \tag{10}$$

where

$$G_1 = (D - 1)S + H \qquad H = \left(\frac{1}{\alpha R} - C\right)\left(1 - \epsilon^{\alpha t_2}\right)$$

$$G_2 = (D - 1)P\omega \qquad S = P\alpha - C$$

$$G_3 = (D - 1)SB + HD \qquad B = \epsilon^{\alpha t_2}.$$

Referring to Fig. 26A it will be seen that t_2 is 0 if the input voltage is just sufficient to make the grid positive, i.e., if $E = -E_0$; while on

the other hand t_2 will not exceed π/ω as E approaches infinity. Hence, if from equation (10) we obtain corresponding pairs of t_1 and t_2 by substituting values of t_2 ranging from $\omega t_2 = 0$ to $\omega t_2 = \pi$ and solving for t_1, we may substitute the pairs of values so obtained in (9), thereby arriving at a relation between E and t_1. Corresponding pairs of these two latter quantities can finally be substituted in (3) thus obtaining a relation between E and Q_1/C.

From (1b) we may express the departure from perfect compensation as a voltage ΔV which would have to be added to the condenser voltage to bring about this ideal condition. Viz:

$$\Delta V = \frac{E}{2} + \frac{E_0}{2} - \frac{Q_1}{C}. \tag{11}$$

By inserting corresponding values of E and Q_1/C, as obtained in the preceding paragraph, the precision of compensation obtained with any given set of parameters may be calculated.

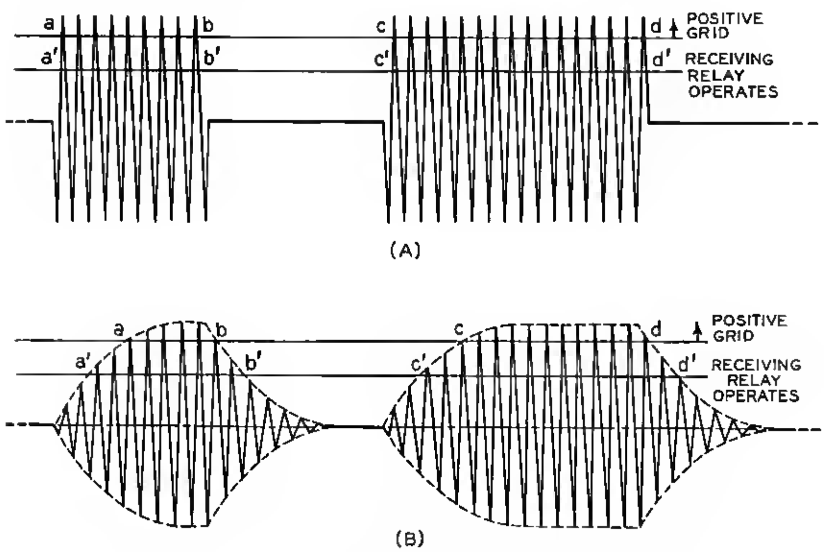

Fig. 27—Function of level-compensator relay. *A*. Square signal. *B*. Rounded signal.

Signaling Condition

Figure 27*A* shows the form which the received signals would have if the transfer admittance of the circuit were independent of frequency. If the level compensator consisted only of the simple condenser-resistance circuit shown in Fig. 25*A*, a large part of the

charge accumulated during a mark would be dissipated during the following space, and since both marks and spaces continually change in relative lengths, this would give rise to characteristic distortion. This difficulty could be taken care of by having a relay operating in unison with the receiving relay and serving to disconnect the leakage resistance R_C during spaces in the manner shown in Fig. 6. Actually, however, the presence of the channel filters causes the received signals to resemble more nearly Fig. 27*B*. This leads to a further difficulty due to the fact that the charging intervals *ab*, *cd*, etc., are shorter than the periods $a'b'$, $c'd'$, etc., during which the receiving relay is closed. To remedy this, the compensator relay is biased towards spacing by means of the resistance *AB* (Fig. 6) and associated battery; the operating impulses being first rounded off by the resistances, condenser, and inductance in the *wave shaping circuit* to make them susceptible of such time bias. A necessary condition to be fulfilled by this circuit is that it should supply enough energy to the compensator relay to operate it even under conditions of extreme bias.

Drift

Returning to Fig. 27*B*, we may consider the bias of the compensator relay as equal to $a'b' - ab$ for the shorter signal or $c'd' - cd$ for the longer one. These biases are, of course, equal time intervals which we will denote by δ. From this it can readily be shown that in a given period—one second for instance—the grid will be conducting during a longer time for a group of long signals than for a group of short ones. Thus, let it be assumed for example, that $c'd' = 2a'b'$ and let n be the number of marking conditions of length $a'b'$ in a given interval; we have for the cumulative charging time in the two cases:

$$T_A = n(a'b' - \delta)$$

$$T_B = \frac{n}{2}(c'd' - \delta) = n\left(a'b' - \frac{\delta}{2}\right),$$

whence

$$T_B = T_A + \frac{n\delta}{2}.$$

It follows that the charge on condenser C is greater for the longer signals. If, therefore, the receiving circuit is adjusted to give unbiased signals when dot signals at the rate of 11 d.p.s. are received, similar signals at 23 d.p.s. will be biased positively. Experience shows that an adjustment which gives zero bias with 11 d.p.s. dots will give substantially unbiased signals with the standard test-sentence; hence

circuits adjusted with 23 d.p.s. dots should be given a small initial positive bias.

It will be noted that the effective voltage available for charging the condenser is not constant throughout the interval *ab*. The maximum value which it can attain, and does attain if the signal is sufficiently long, equals the effective charging voltage during steady marking; on the other hand if the signal is very short, this value may never be reached. It follows that the charge accumulated by the condenser for any kind of intermittent signals is always less than that for steady marking; the amount of the discrepancy depending on the wave shape of the envelope.

As a result of these effects, and other similar conditions which tend to modify the average charge on the condenser depending on the character of the received signals, there is a perceptible amount of characteristic distortion manifesting itself in a fortuitous manner during the reception of ordinary text.

The change in the mean condenser charge can easily be observed if after a steady marking condition has been maintained for a few seconds, dots are suddenly impressed on the circuit and their bias observed. The latter will be found to *drift* as the charge assumes a new mean value. In practice, an adjustment is made for this by observing the change in voltage across the condenser under these two conditions and adjusting the compensator-relay bias to maintain the drift within limits which experience has shown to give minimum distortion with ordinary text.

Bibliography

1. Colpitts, E. H. and Blackwell, O. B., "Carrier Current Telephony and Telegraphy," *A. I. E. E., Trans.*, Vol. 40, pp. 205–300, 1921. (Has extensive bibliography.)
2. Bell, J. H., "Carrier-Current Telegraphy," *Bell Labs. Record*, Vol. 1, pp. 187–192, Jan., 1926.
3. Hamilton, B. P., Nyquist, H., Long, M. B., and Phelps, W. A., "Voice Frequency Carrier Telegraph System for Cables," *A. I. E. E., Trans.*, Vol. 44, pp. 327–332, 1925.
4. Nancarrow, F. E., "Line Telegraphy: More Voice Frequency Channels," *Electrician*, Vol. 122, p. 108, Jan. 27, 1939.
5. Harrison, H. H., "Printing Telegraph Systems and Mechanisms," Lond., Longmans, 1923.
6. Bell, J. H., "Printing Telegraph Systems," *A. I. E. E., Trans.*, Vol. 39, pp. 167–230, 1920.
7. Pierce, R. E., "Modern Practices in Private Wire Telegraph Service," *A. I. E. E. Trans.*, Vol. 50, pp. 426–435, 1931.
8. Gray, Elisha, "Nature's Miracles," Vol. 3, *Electricity and Magnetism*, pp. 126–128. N. Y., Fords, Howard and Hulbert. 1900.
9. "Il y a Cinquante ans: Essai du telegraphe harmonique de E. Gray," *Rev. Gen. de l'Elec.*, Vol. 32, pp. 361–362, 1932.
10. Watson, E. F., "Fundamentals of Teletypewriters Used in the Bell System," *Bell Sys. Tech. Jour.*, Vol. 17, pp. 620–639, 1938.
11. Pierce, R. E. and Bemis, E. W., "Transmission System for Teletypewriter Exchange Service," *Bell Sys. Tech. Jour.*, Vol. 15, pp. 529–548, 1936.

12. Clark, A. B., "Telephone Transmission over Long Cable Circuits," *A. I. E. E., Trans.*, Vol. 42, pp. 86–96, 1923.
13. Green, E. I., "Transmission Characteristics of Open-Wire Telephone Lines," *A. I. E. E., Trans.*, Vol. 49, pp. 1524–1535, 1930.
14. Affel, H. A., Demarest, C. S., and Green, C. W., "Carrier Systems on Long Distance Telephone Lines," *Bell Sys. Tech. Jour.*, Vol. 7, pp. 564–629, 1928; *A. I. E. E., Trans.*, Vol. 47, pp. 1360–1387, 1928.
15. O'Leary, J. T., Blessing, E. C., and Beyer, J. W., "Improved Three-Channel Carrier Telephone System," *Bell Sys. Tech. Jour.*, Vol. 18, pp. 49–75, 1939.
16. Cowley, G. W., "Volume Limiter Circuits," *Bell Labs. Record*, Vol. 15, pp. 311–315, June, 1937.
17. Peterson, Eugene and Keith, C. R., "Grid Current Modulation," *Bell Sys. Tech. Jour.*, Vol. 7, pp. 106–139, 1928.
18. Nyquist, H., Shanck, R. B., and Cory, S. I., "Measurement of Telegraph Transmission," *A. I. E. E., Trans.*, Vol. 46, pp. 367–376, 1927.
19. Shanck, R. B., Cowan, F. A., and Cory, S. I., "Recent Developments in the Measurement of Telegraph Transmission," *Bell Sys. Tech. Jour.*, Vol. 18, pp. 143–189, 1939.
20. Kupfmuller, K., "Über Einschwingvorgänge in Wellenfiltern," *E. N. T.*, Vol. 1, pp. 141–152, 1924.
21. Nyquist, H., "Certain Topics in Telegraph Transmission Theory," *A. I. E. E., Trans.*, Vol. 47, pp. 617–644, 1928.
22. Stahl, H., "Versuche über eine gunstige Verteilung der Tragerwellen in der Wechselstromtelegraphie," *T. F. T.*, Vol. 19, pp. 340–347, 1930.
23. Herman, J., "Bias Control in Telegraph Communication," U. S. Patent 1,886,808, Nov. 8, 1932; "Transmission Level Control in Telegraph Signaling Systems," U. S. Patent 1,943,478, Jan. 16, 1934.
24. Cash, C. C., "Protection against Lightning Interference," *Bell Labs. Record*, Vol. 15, pp. 125–128, Dec., 1936.
25. Trucksess, D. E., "High Precision Speed Regulator," *Bell Labs. Record*, Vol. 13, pp. 187–190, Feb., 1935.
26. Fry, J. R. and Gardner, L. A., "Polarized Telegraph Relays," *A. I. E. E., Trans.*, Vol. 44, pp. 333–338, 1925.